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March 1994

Water Quality Research Plan for Management Systems Evaluation Areas (MSEA's)

An Ecosystems Management Program

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Water Quality Research Plan for Management Systems Evaluation Areas (MSEA's)

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in cooperation with
State Agricultural Experiment Stations
Extention Service
Soil Conservation Service
Economic Research Service
U.S. Geological Survey
U.S. Environmental Protection Service

Abstract

U.S. Department of Agriculture. 1994. Water Quality Research Plan for Management Systems Evaluation Areas (MSEA's): An Ecosystems Management Program. U.S. Department of Agriculture, Agricultural Research Service, ARS–123.

Agricultural chemicals are causes of increasing concern as contaminants of ground water, which is vital for human consumption and other uses. The Management Systems Evaluation Area program (MSEA) was begun to research the economic viability of alternative farming methods in the Midwest in order to reduce our dependence on these chemicals. By targeting their research in five distinct areas, scientists will assess landscapes and farming systems for their vulnerability to water contamination from farm chemicals, provide information about the behavior and effects of agrichemicals on the ecology, and identify environmentally sound farming systems that are acceptable to producers. This publication describes the planned research, goals, structure, and timetable of the ecosystem-based program.

Keywords: Agricultural experiment farms, agricultural research, aquifers, farm management, farming methods, fertilizers, insecticides, pesticides, soil contamination, soil management, water pollution.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that uses discussed here have been registered. All uses of pesticides must be registered by appropriate state or Federal agencies or both before they can be recommended.

While supplies last, single copies of this publication may be obtained at no cost from Dale A. Bucks, USDA-ARS, BARC-West, Building 005, Room 233, Beltsville, MD 20705.

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Contents

Overview

Agricultural lands, including pasture, range, and croplands, occupy 390 million ha—almost half the land area of the continental United States. Another 265 million ha are devoted to forests. Each year, about 450 million kg of pesticide active ingredients are used in agricultural production (Gianessi and Puffer 1990). To produce food and fiber crops in the United States, 19 billion kg of fertilizers are applied annually.

The development of agricultural fertilizers and pesticides in the 20th century has enormously increased the productivity of American croplands, pastures, rangelands, and forests. While this technology has enabled Americans to feed and clothe themselves and to export food and fiber, the introduction of chemicals into land, water, air, and food has also produced environmental and health hazards.

Nitrate, which is used in fertilizers, for example, has been associated with human health problems, particularly in infants. Some of the widely used pesticides such as atrazine, alachlor, and carbofuran are thought to be linked to cancer, neurotoxicity, birth defects, or reproductive anomalies. Pesticides in surface water may impair aquatic, terrestrial, and wetland ecosystems; reduce the diversity of soil microbial and invertebrate communities; and threaten vertebrate populations through bioaccumulation and habitat fragmentation.

Today, over 50 percent of the impairments in the quality of surface water are attributable to agricultural activities, and some portion of the chemicals from croplands eventually percolate into the ground water vital for human consumption and other uses. A recent U.S. Department of Agriculture (USDA) report cited agricultural activities as the most significant source of ground water contamination (U.S. Department of Agriculture 1989).

A National Survey of Pesticides in Drinking Water Wells conducted by the Environmental Protection Agency (EPA) (1990) estimates that 45 percent of community water system wells and almost 54 percent of rural domestic wells contain detectable amounts of nitrate, and that more than 10 percent of community water system wells and over 4 percent of rural domestic wells contain detectable amounts of pesticides.[1]

[1]Only 1.2 percent of community water system wells and 2.4 percent of rural domestic wells are estimated to contain nitrate amounts that exceed health-based limits. Pesticides are estimated to exceed health-based limits in 0.8 percent of community water system wells and 0.6 percent of rural domestic wells.

Much remains unknown about the potential health and environmental consequences of continued large-scale use of chemicals in agriculture. But we can begin to take steps to learn about the economic viability of alternative methods of cultivation that could reduce the Nation's dependence on agricultural chemicals. Some of these methods include conservation tillage; targeted, low-volume pesticide applications; banded or reduced fertilization; crop rotation; improved water management; and integrated pest management.

The MSEA Program

In response to these human health and environmental concerns, the U.S. Department of Agriculture in 1989 instituted the Water Quality Initiative, a research program guided by the following three principles:

- protection of the Nation's ground water resources from contamination by fertilizers and pesticides without jeopardizing the economic vitality of U.S. agriculture;
- water quality programs that address the immediate need to halt contamination and the future need to alter fundamental farm practices; and
- the ultimate responsibility of farmers for changing production practices to avoid contaminating ground and surface waters.

The Management Systems Evaluation Area (MSEA, pronounced mee-sa) program emerged from the USDA Initiative. The purpose of the MSEA program is (1) to evaluate the effects of chemicals on ground water in the Midwest in areas representing a variety of soil, geologic, and climatic conditions and (2) to develop a protocol of best management practices that safeguard the ground water from chemical contamination while satisfying the economic, environmental, and social needs of the region. Results are to be disseminated throughout the Midwest and elsewhere, as applicable.

This report provides an overview for interagency staff involved with the MSEA program, for policymakers interested in the direction of the Water Quality Initiative, and for scientists and researchers seeking to implement similar or complementary projects.

The report describes research goals, methodology, and project administration; discusses each MSEA project, including hydrologic, socioeconomic, and ecologic research; and reviews crosscutting activities such as quality assurance and data base management.

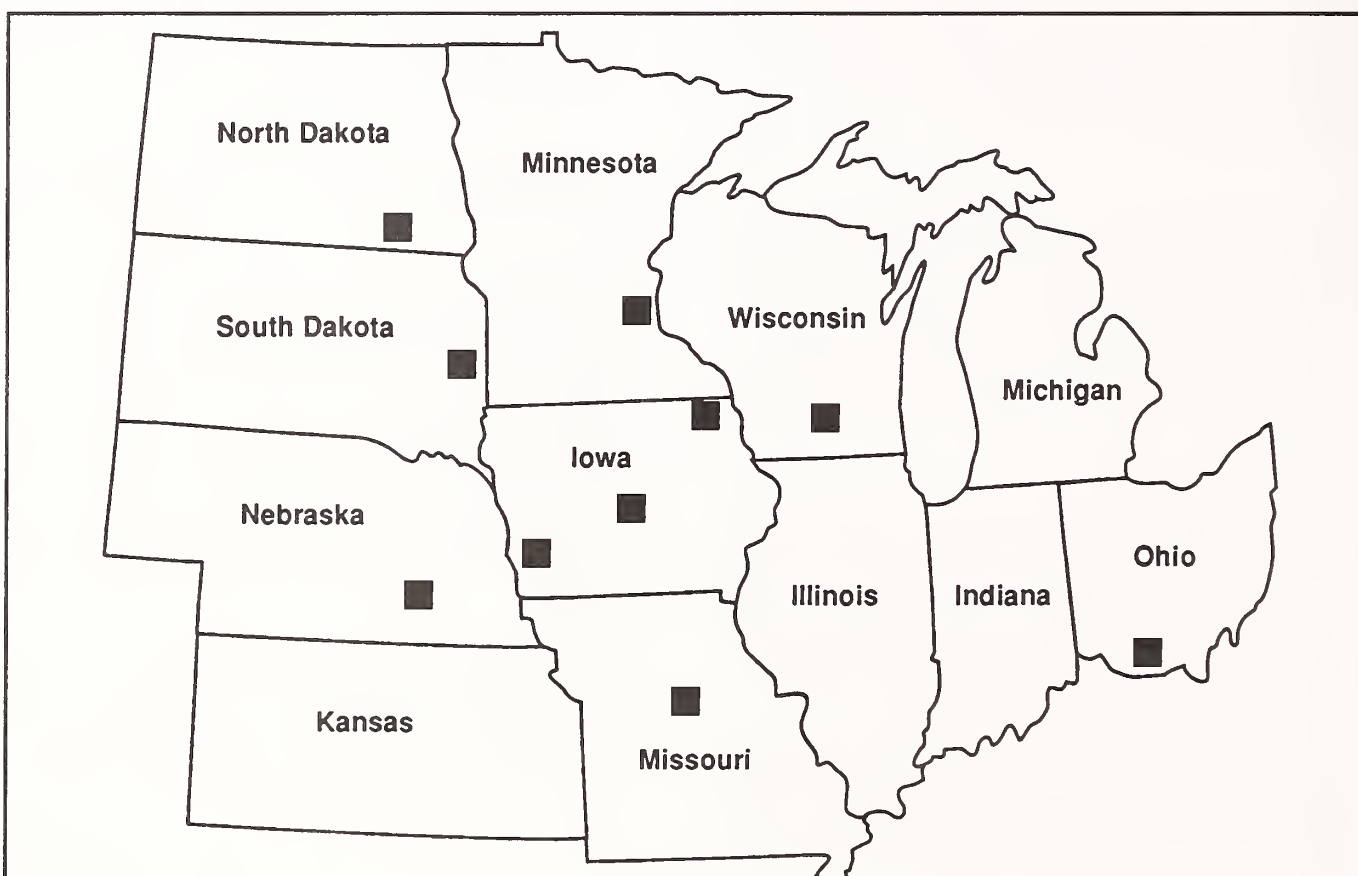
The MSEA program uses an ecosystem management approach that integrates economic and social factors to maintain and enhance the quality of the environment for current and future needs. The Midwest was selected for pilot research because ground water and surface water there were determined to be at risk. One of the most intensively farmed areas in the United States, the Midwest produces more than half of all U.S. corn and soybeans and uses more than half of the nation's fertilizers and pesticides. About 35 percent of the farms employ conservation tillage practices that often use large amounts of pesticides and fertilizers.

Twelve states responded to USDA requests for proposals in 1990 (fig. 1). Within a framework of scientific merit, availability of staff and funds, and estimated costs, each area also had to meet the following criteria to qualify for the program:

- derive over 50 percent of its agricultural production from corn and soybeans;
- overlie a significant aquifer;
- confront a real or potential water quality problem as a result of agricultural production practices;
- be affected by nonpoint contaminant sources that the MSEA project could manage;
- show the time needed for agricultural chemicals to move significantly or reach the aquifer, thus demonstrating that certain measurements were possible within the timeframe of the project;
- identify the sources, quantity, and temporal variation of waters available for chemical transport;
- be amenable to the control of MSEA directors for the 5-year duration of the project; and
- be able to document the research, monitoring, and technology transfer issues.

Of the 12 states, five were chosen, using a peer-review process. These five MSEA's represent major subdivisions of the Corn Belt based on geologic materials, location and size of aquifers, depth to the water table, and proportion of the land in corn and soybeans. The five MSEA's and their project names are listed following:

Figure 1. MSEA sites



- Iowa, "Evaluation of the Impact of Current and Emerging Farming Systems on Water Quality";

- Minnesota, "Midwest Initiative on Water Quality: Northern Corn Belt Sand Plain";

- Missouri, "Alternative Management Systems for Enhancing Water of an Aquifer Underlying Claypan Soils";

- Nebraska, "Management of Irrigated Corn and Soybeans to Minimize Ground Water Contamination"; and

- Ohio, "The Ohio Buried Valley Aquifer Management Systems Evaluation Area."

Project Administration

The program began in FY 1990. It is cooperatively administered by the Agricultural Research Service (ARS), Cooperative State Research Service (CSRS), Extension Service (ES), Soil Conservation Service (SCS)—all of the U.S. Department of Agriculture (USDA)—the U.S. Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), and a steering committee, which consists of principal investigators from the five state project sites and which oversees a structure of technical and nontechnical subcommittees staffed by people from the Federal, state, and private sectors (fig. 2). A timeline of activities for the 5 years of the program and beyond is charted in figure 3.

Adherence to several management objectives will ensure (1) comparability, transferability, and accuracy of results; (2) development of a "core" data base at each site in formats enabling the sharing of data; and (3) dissemination of research results to other Federal and state programs, as well as to scientists, regulators, policymakers, farmers, and the public.

The Research Framework

Products
Specific products expected from MSEA research include

- identification of environmentally sound farming systems that are acceptable to producers,

- assessments of landscapes and farming systems for their vulnerability to water contamination from farm chemicals,

- information about the effects of farm chemicals on a region's ecology,

- information about the suitability of management systems for specific farms in the Midwest, and

- basic understanding of the behavior of farm chemicals in the environment.

Research will be conducted in four major categories: (1) farming systems (the effect of farm management on water quality and profitability), (2) hydrologic processes (the movement and action of water), (3) ecosystems (chemical effects on ecosystems); and (4) socioeconomic systems (how the adoption of modified farming systems affects social and economic systems).

Objectives
Six objectives will guide the course of research.

1. To measure the impact of prevailing and modified farming systems on the chemical constituents of ground and surface water.

   This objective embodies describing the location and characteristics of earth materials that are part of the farming and hydrologic systems; researching water chemistry to determine the links between contamination, geologic and landscape characteristics, and farming practices; and tying management systems and their chemical inputs to chemical constituents in water resources.

2. To identify and increase understanding of the factors and processes that control the fate and transport of agricultural chemicals.

   Information about the processes by which agricultural chemicals move, change, and persist from sites of application through the hydrologic system will be gathered at the individual MSEA projects and then translated into cause-effect relationships between farm management systems and water quality. Measurements of physical, chemical, and biological processes will be related to hydrologic and farming system characteristics not only to broaden understanding of basic processes but also to determine how these processes may affect the fate of chemicals outside the initial research areas.

3. To assess the impact of agricultural chemicals and practices on ecosystems.

   At selected MSEA locations, data will be obtained on the environmental benefits of various farming systems, measures will be identified for preventing ecological degradation from farming practices, and tools will be found for implementing water quality management programs on area, watershed, and regional scales.

4. To assess the benefits of using modified farming systems in the Midwest.

   Areas will be identified where water resources face the greatest risks of contamination; options to improve the

Figure 2. Administrative structure

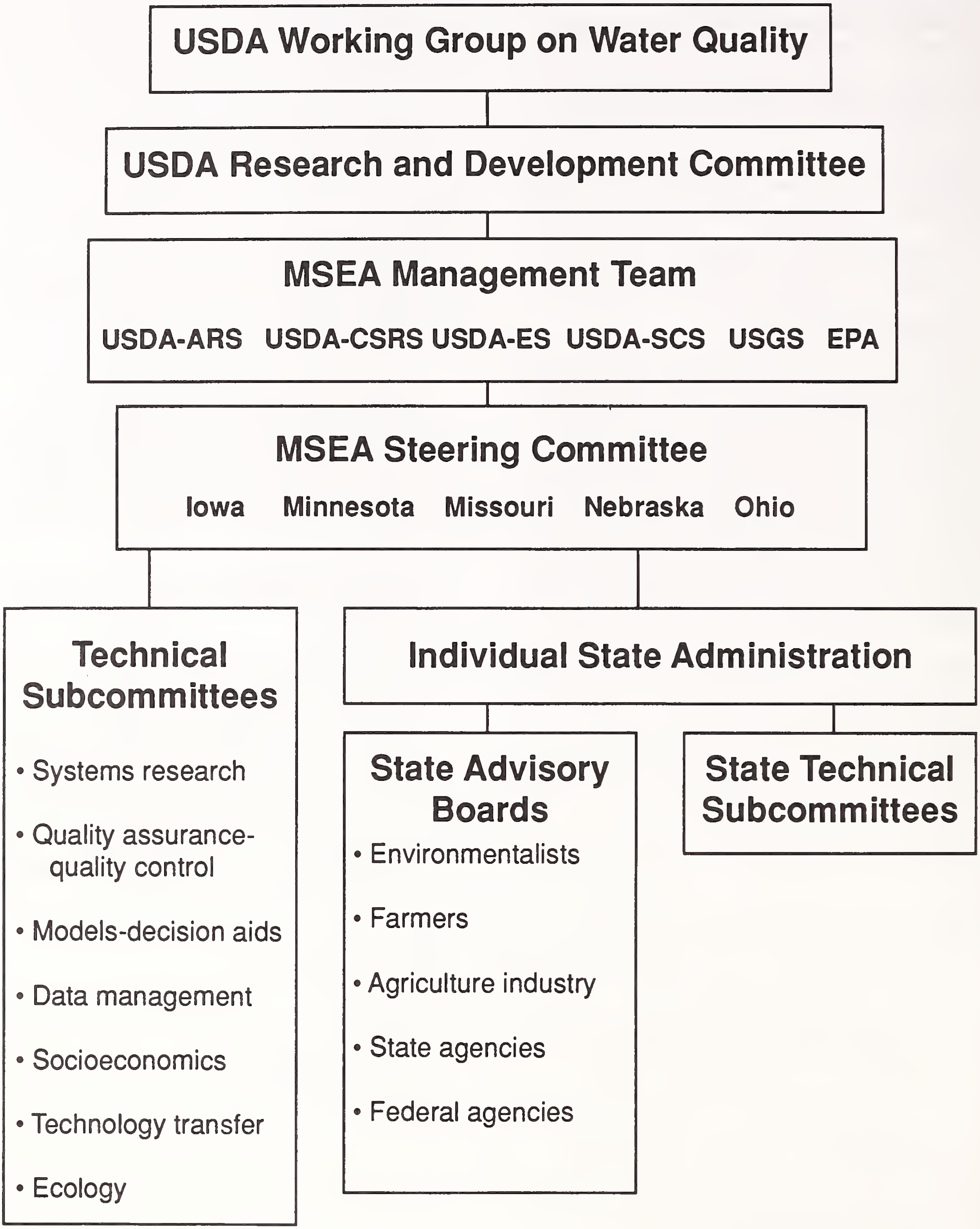
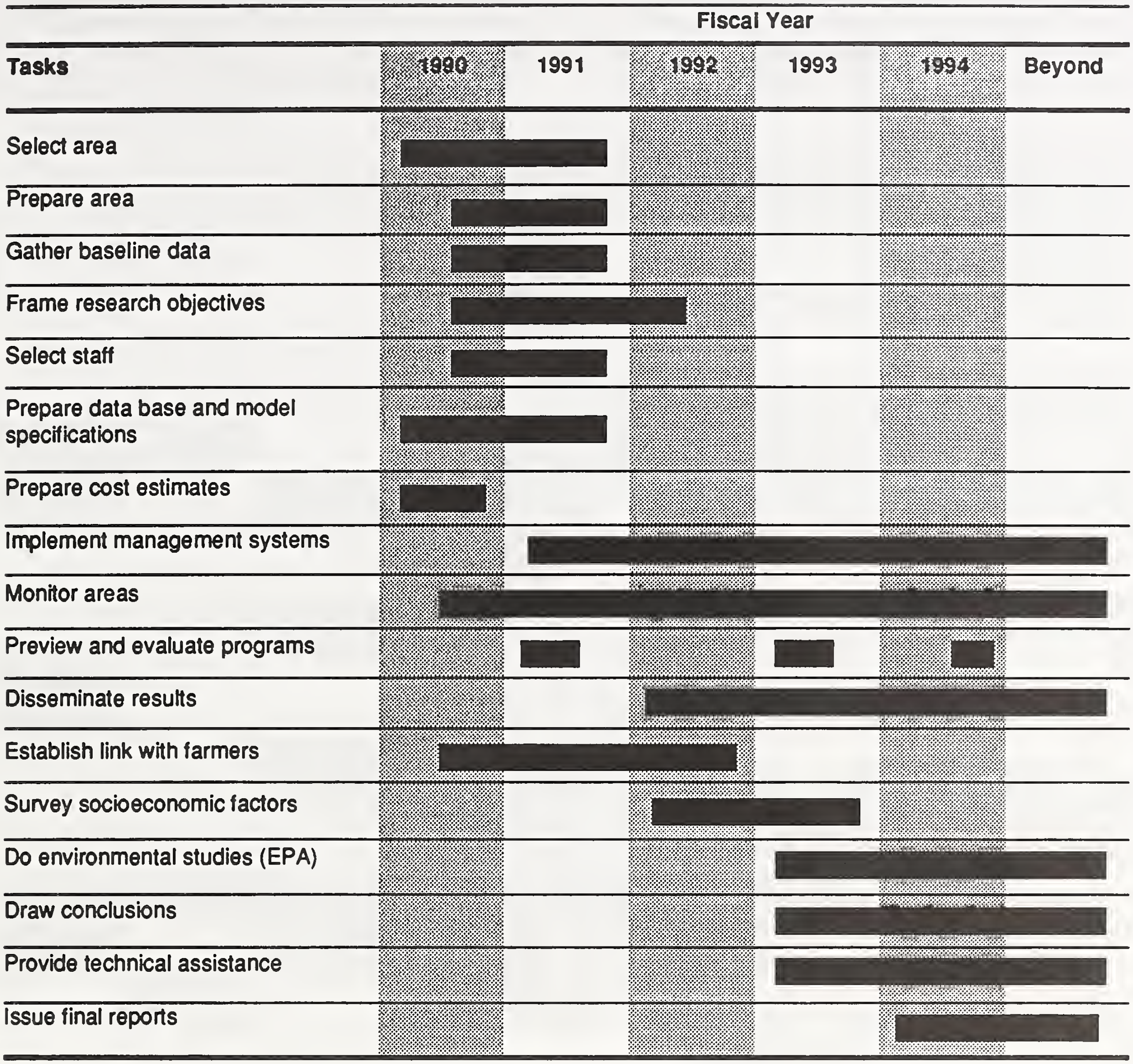


Figure 3. Timeline of MSEA activities



water quality will be tested from among the modified farming systems.

5. To evaluate the social and economic impacts of adopting modified farm management systems.

   Adoption of a modified farming system is influenced by short- and long-term profitability, capital costs, ease of making a transition, and farmers' attitudes toward the change. A farming system must be profitable, and any new technology must be accessible and affordable in order to be adopted. In cases where a particular farming system will improve water quality but is not as profitable as standard practice, state and Federal technical assistance and cost-sharing may be required to stimulate adoption. Data will be obtained on farmers' decision-making processes and experiences when replacing farm practices.

6. To transfer the appropriate technology to other agricul tural areas.

   Farmers must have the knowledge and technical means to respond independently and voluntarily to farm-based water quality concerns. Research results about water contamination and farm management systems that protect water resources will be communicated to producers and other appropriate decision makers.

Component Research

Figure 4 identifies elements of the farm management systems to be studied at each MSEA site, and figure 5 shows the range of research tasks. By comparing one or more cropping systems at each site with a reference cropping system in wide use in the region, researchers can continuously evaluate changes in water quality and profitability. The cropping systems chosen will be suited to the soil, geology, climate, irrigation, nitrogen and pesticide needs, and other features of each area.

Figure 4. Elements of the farm management systems to be studied

	Iowa			Minnesota				Missouri	Nebraska	Ohio
Element	Nashua	Des Moines Lobe	Deep Loess Region	WI	MN	ND	SD			
Cropping system										
Continuous corn	■	■	■		■				■	■
Corn-soybean rotation	■	■		■	■	■	■	■		■
Potato-sweet corn rotation					■					
Corn-sorghum rotation								■		
Corn-soybean-wheat rotation										■
Corn-sorghum-wheat rotation								■		
Quality monitoring										
Ground water	■	■	■	■	■	■	■	■	■	■
Surface water		■	■		■			■		■
Irrigation				■	■	■	■		■	
Subsurface drainage	■	■								
Reduced tillage	■	■	■	■	■	■	■	■	■	■
Nitrogen application										
Soil testing	■	■	■	■	■	■	■	■	■	■
Tissue testing				■	■	■	■		■	
Pesticide application										
Labeled rates	■	■	■	■	■	■	■	■	■	■

Figure 5. Range of MSEA research tasks

Research Task	Iowa	Minnesota	Missouri	Nebraska	Ohio
Fundamental research					
Water and solute transport	■	■	■		■
Transformation processes	■		■	■	■
Sorption processes	■				■
Biological processes	■		■	■	■
Evaluation of farming systems					
Modified practices	■	■	■	■	■
Technology evaluation		■	■	■	
Effects on soils	■	■	■	■	■
Socioeconomic consequences	■		■	■	■
Development of farming systems					
Component research	■	■	■	■	■
Chemical application methods		■	■	■	
Diagnostic tools	■	■	■	■	
Spatial data					
Compile, integrate, transfer	■	■	■	■	■
Evaluate	■	■	■	■	■
Development of decision aids					
Evaluate and develop models	■	■	■	■	■
Target decision aids		■		■	
Develop economic decision aids	■		■	■	■
Technology transfer to users					
Field days and demonstrations	■	■	■	■	■
Newsletters	■	■	■	■	■
Service functions					
Laboratory and sampling methods	■		■		■
Standards and glossary	■				■
Effects on ecosystems					
Surface water and wetlands	■	■	■		
Terrestrial land	■		■		■

Because economic considerations will be the dominant factor in whether farmers adopt modified cropping systems, various combinations of farm practices that could be profitable will be integrated into cropping systems which have a high potential to minimize ground water contamination. In many cases, these technologies are currently available but are not commonly used because of perceived inconveniences. Occasionally, management techniques that are still under scientific development and not commonly available to producers (plant tissue testing is one example) will be incorporated into experimental systems, such as fertigation or spoke injection of fertilizers using high-clearance vehicles.

Data Collection and Management

Common types of data will be collected at all locations to facilitate evaluation and comparison of the cropping systems (table 1). Chemical inputs to the system will be quantified. Data obtained from samples from the unsaturated zone will aid scientists in determining the fate of pesticides in soil and characterizing the relative movement of nitrate in the root zone. Ground water samples will be used to characterize the quality of water that percolates through the unsaturated zone and into the aquifer. The frequency of sample collection at each location will vary depending on the cropping systems, soils, and climate, but ground water will be collected at least quarterly at all locations to enable regional comparisons.

Table 1. Data Collected and Procedures To Be Used at Each MSEA Site

Type of Data	Standard Procedure
Climate	
Temperature, solar radiation, windspeed, wind direction, relative humidity, precipitation, soil temperature	Automated weather station, programming, and quality assurance-quality control provided by National Soil Tilth Laboratory
Atmospheric deposition, liquid phase, dry phase	National Atmospheric Deposition Project-approved procedures for chemical analyses and quantity measurements
Plant biomass	
Grain yield	Adjusted to market standards
Stover yield	Aboveground plant biomass excluding grain (dry weight)
Plant nitrogen utilization	
Grain nitrogen uptake	Kjeldahl procedure including nitrate-nitrogen or Dumas combustion
Stover nitrogen uptake	
Unsaturated zone	
Soil water content	Neutron probe, calibrated locally
Gravimetric water content	Surface soil
Pesticide and nitrate content of soil cores	Quality assurance-quality control procedures for sample collection and analyses

Table 1. Data Collected and Procedures To Be Used at Each MSEA Site (continued)

Type of Data	Standard Procedure
Chemicals in water	
Pesticides Nitrate	Quality assurance-quality control procedures for sample collection and analyses
Site characteristics	
Soils	
Physical properties Chemical properties	Standard National Soil Survey Laboratory procedures for selected physical and chemical parameters
Descriptions	Soil Conservation Service soil survey procedures
Topography, geology, hydrology, aquifer descriptions, surface drainage, subsurface drainage	U.S. Geological Survey techniques used in water resources investigations

A set of standard operating procedures for all common chemical and physical measurements will ensure the quality and reliability of the data (table 1). Procedures for collecting, handling, and analyzing samples are specified in quality assurance-quality control standards (discussed on *page 11*). Standard lab procedures will be employed to analyze other types of data that are not likely to change over the duration of the project (such as soil texture, water-holding characteristics, and chemical properties) and that will ultimately be used in simulation models or to aid in data interpretation.

Specialized data will be collected at each MSEA site, and these will also be gathered and analyzed using standard procedures (table 2).

Table 2. Standard Data To Be Collected at Each MSEA Site

Type of Data	Time of Collection
Total aboveground biomass	**Corn:** 6- to 7-leaf stage of silking, physiological maturity **Soybeans:** V3 veg growth stage, R1 flowering, R6 full seed
Plant biomass nitrogen	**Corn:** 6- to 7-leaf stage of silking, physiological maturity **Soybeans:** V3 veg growth stage, R1 flowering, R6 full seed
Harvestable yield	**Corn:** harvest **Soybeans:** harvest
Root biomass	**Corn:** silking **Soybeans:** R1 flowering
Soil water content	Weekly Biweekly (at depths of 15, 30, 90, 150 cm)
Pesticides (in soil cores taken at depths of 15, 30, 90, 150 cm)	Prior to spring tillage (within 1 month of planting) and 2 weeks past planting **Corn:** silking, physiological maturity **Soybeans:** R1 flowering, R6 full seed
Nitrogen (in soil cores taken at depths of 15, 30, 90, 150 cm))	Prior to spring tillage (within 1 month of planting), 2 weeks past planting, and 2 weeks after each fertilizer application **Corn:** silking, physiological maturity **Soybeans:** R1 flowering, R6 full seed
Pesticides and nitrates and nitrates (in ground water)	January, April, July, October

Supporting Research
Scientists at each MSEA site will also conduct supporting research that enables fuller evaluations of components of the cropping systems. While component research will not be duplicated at each MSEA site, promising new management practices will be incorporated into existing cropping systems, if appropriate, or evaluated at other MSEA locations.

Two MSEA sites—Iowa and Minnesota—include satellite locations, which will be particularly valuable in evaluating aspects of the cropping systems that take years to manifest themselves (for example, the effects of crop rotation on soil structure, nitrogen cycling, and water infiltration). Several of these satellites will also test scientific equipment as possible future farm management tools.

Hydrologic Research

Pesticides and Fertilizers
Water in all parts of the hydrologic system will be analyzed for nitrate, atrazine, alachlor, and carbofuran—the principal chemicals used in corn and soybean production in the Midwest. Except for carbofuran, all of these chemicals have been reported in shallow aquifers and streams in many parts of the region. Analyses for other pesticides will be performed in the areas where they are applied.

Water will be analyzed for the presence of nitrogen species to understand their distribution in water and the processes that modify them, particularly as they travel to and in ground water. Water will also be analyzed for the degradation products of atrazine and alachlor, specifically desethylatrazine, desisopropylatrazine, chloroalachlor, and hydroxyalachlor. At the time of this writing, data on the concentrations of other degradation products are limited by the lack of adequate or inexpensive methods of water analysis, but at least one MSEA laboratory plans to develop analytical methods for these compounds.

Other Parameters
In addition to standard chemical measures, ecological parameters will be used as measures of surface water quality. While the health of an agroecosystem is directly related to water quality, concentrations of chemicals in water are not always precise indicators of an ecosystem's health. An ecosystem may still be impaired, for example, even though chemical concentrations fall below safety and health thresholds. Damage may stem from a combination of factors, including water chemistry, eroded soils, land use modifications, and changes in stream geometry. Techniques are being developed to differentiate the causes of impairment in an aquatic community so that appropriate farm management systems can be selected as safeguards.

Other important research will include (1) how contaminated ground water interacts with surface water and contributes to surface water contamination; (2) the effects on aquifers of practices at the land surface, to be studied in the highly permeable sand and gravel of Minnesota, Nebraska, and Ohio; and (3) conditions under which chemicals affect streams and wetlands more than they do aquifers, which will be researched in the permeable loess in Iowa, the less permeable claypan soils of Missouri, and the much less permeable Wisconsin till in Iowa.

Table 3 summarizes components of the hydrologic system that will be monitored. Initial work in each MSEA involved characterizing the water resources to establish the rates and quantities of water moving into and through the aquifers and streams. Much of this work was accomplished in the first 2 years by analyzing information on hand about the five areas and by establishing precipitation stations, lysimeters, tensiometers, wells, and stream gauges for continuous physical and chemical measurements.

Expected Changes in Water Quality
As modified farm management systems are implemented, target chemicals in water resources are expected to decrease. Nitrate concentrations in aquifers are expected to decrease in most MSEA's, and overall nitrate levels are expected to decrease in streams where changes will be measured as differences in seasonal concentrations and loads.

These hypothesized improvements in water quality serve as targets against which the success of modified farming systems can be measured. These expectations will be refined as identification proceeds of the chemical constituents in the water at each MSEA and as understanding increases about the effects of components of each management system on specific hydrologic settings.

Quality Assurance and Quality Control

A Quality Assurance/Quality Control (QA/QC) Technical Subcommittee will ensure that reported results are of the highest reasonably obtained quality. This subcommittee developed protocols for the wide variety of procedures needed when collecting samples and data.

Water Samples
Using the protocols, individual MSEA laboratories will process their own water samples collected on site. Data analyses will then be independently verified by an external QA/QC laboratory.

Soil Samples
Soil samples will be collected on site and sent for analysis of pesticide and nitrate content to the ARS National Soil Tilth Laboratory, in Ames, IA. The external laboratory will independently determine the concentrations of compounds within a soil sample and compare their results to those of the National Soil Tilth Laboratory. Procedures are also in place for processing samples at individual sites.

Table 3. Components of the Hydrologic System To Be Monitored

MSEA	Unsaturated Zone	Saturated Zone	Surface Water
Iowa			
Walnut Creek	Tile drainage Evapotranspiration	Alluvial aquifer	Stream, wetland
Treynor*	Recharge to deep aquifer		Stream
Nashua*	Tile drainage		
	Recharge to deep aquifer		
Minnesota			
Princeton, MN	Direct recharge	Sand plain aquifer	Stream, wetland
Aurora, SD*		Sand plain aquifer	
Oakes, ND*	Evapotranspiration	Sand plain aquifer	
Sand Plains, WI*	Sand plain aquifer		Stream
Missouri			
Goodwater Creek	Recharge to deep aquifer	Fractured clay pan	Streams
Nebraska			
Platte alluvium	Direct recharge	Alluvial aquifer	Losing stream
Ohio			
Scioto alluvium	Direct recharge	Alluvial aquifer	Streams, wetland

*Satellite

The external laboratory will also prepare standard reference samples to be sent quarterly to each MSEA laboratory, review results from each MSEA laboratory, and analyze overall quality and consistency among laboratories. The technical subcommittee will review all reports from the external lab and work with it on remedial actions. Together, the subcommittee and external laboratory will evaluate any new protocols or analytical procedures.

The minimum limits required to detect each compound are shown in table 4, along with the acceptable levels of confidence. The quality control procedures are intended to ensure that these detection limits are maintained throughout the life of the MSEA project. In most cases, the minimal detection limits are one to two orders of magnitude less than the maximum contaminant levels set by EPA.

Table 4. Analytical Quantitative Limits in Water and Soil

Compound	Quantitative Limit		Precision Limit
	Water	Soil	(Water and Soil)
Atrazine	0.2 µg/L	5 ng/g	±3 SD
Alachlor	0.2 µg/L	5 ng/g	±3 SD
Metribuzin	0.2 µg/L	5 ng/g	±3 SD
Metolachlor	0.2 µg/L	5 ng/g	±3 SD
Carbofuran	0.5 µg/L	5 ng/g	±3 SD
Nitrate	1.0 µg/l	2.5 mg N/g	±10%

Models and Decision Aids

Models can extend available information in time and space, enabling decisions to be made that might otherwise amount to educated guesses. Water quality models and other decision aids are tools that conservationists, environmentalists, and Federal and state agencies can use to estimate agricultural contributions to water contamination.

Many mathematical models are now available that represent physical, chemical, and biological processes. These range from empirical models that can quickly simulate 1 or more years of field practices and require few inputs and decision rules, to physically based models that require many inputs and use complex equations representing many real-life processes.

The MSEA program will provide information about a range of geographic and hydrologic conditions to extend the range or scale of many models. Models will be selected for comparison from MSEA sites. Protocols will be developed for evaluating the models using MSEA data, and linkages will be established with model developers and users to assure that input data are compatible with model requirements.

Applying Results to Larger Regions

It is hoped that research findings can be applied to larger areas of the Midwest. Areas where water and ecological resources are most degraded will be identified and the options to improve water quality will be projected onto them. Meeting this goal involves five steps. Steps 1–3 will identify areas where modified systems are needed. MSEA evaluations will pinpoint the management systems most likely to improve water quality and maintain profitability. Step 4 will define the locations where these systems will yield potential improvements in water quality similar to those found at the MSEA sites, only on a larger scale. Step 5 projects potential benefits.

1. Identify the occurrence—spatially and temporally—of targeted agricultural chemicals in Midwestern water resources.

   The occurrence of targeted classes of chemicals in aquifers, streams, lakes, and reservoirs throughout the Midwest will be recorded. The chemicals atrazine, alachlor, carbofuran, and nitrate were selected to repre sent the following broader classes of compounds: the triazine herbicides, the acetanilide herbicides, the carbamate insecticides, and plant nutrients, respectively. Other potential agricultural contaminants, such as sediment and phosphorus, as well as ecological indicators of contamination may be considered if resources permit.

2. Characterize the environmental and anthropogenic resource base of the Midwest. Data will be assembled on environmental resources such as climate, soils, hydrology, topography, and geology and on anthropogenic characteristics such as land use (particularly cropping patterns), chemical use, and water use. A geographic information system (GIS) data base will be used to assemble the data for analyses.

3. Associate characteristics of this Midwestern resource data base with water quality attributes.

   The GIS will associate many factors from the resource base with water quality characteristics on several scales. Once associations on the subregional scale are verified by tests, it will be possible to rank subregions according to their need to improve or protect water quality. The relative contributions of sources of contamination will also be identified.

4. Define the subregions where modified management systems can be applied.

   The environmental factors that characterize a MSEA will be combined with factors from its farm management systems in order to derive other locations where modified management systems would produce maximum water quality benefits. Subregions will be defined beginning with estimates from regional data bases. Scientists will then measure critical factors in the field in selected areas to confirm the accuracy of the regional data and to assure applicability of the management systems to the subregion. Adaptations to the systems will be considered as ways to expand the geographic applicability of the farm management systems.

5. Assess the projected benefits of implementing modified farming systems in the Midwest.

   The final step is regional assessment, using conceptual, statistical, and other techniques to project water quality improvements from modified management systems. The projected changes in water quality will be quantified by comparing the occurrence of target chemicals with estimated changes from modified management systems. Management systems can then be implemented and tested to evaluate the water quality improvements. These projections will allow policymakers and producers to make more informed decisions about potential financial and social costs of policy options, as well as to risk affecting relatively large parts of the landscape by changes in management systems.

   Each MSEA will generate three types of data sets: (1) the area's core data, which entails evaluating the management systems for water quality, productivity, and profitability; (2) data generated from specific research activities, which go beyond the core data to answer more basic questions; and (3) the regional data, which typically are a subset of the area's core project. Generally, each MSEA will house core data in a centralized relational data base management system (RDBMS), which uses Structured Query Language (SQL). The five MSEA's are collaborating to develop transferrable data bases, even though different software packages may be used.

Data from the specific research activities will be stored in the researchers' laboratories in a format compatible with importation to the central data base. Regional data may be incorporated into the core data base at the principal investigator's discretion. Each area will also have a regional data base, which will store data to be used in regional analyses, discussed more fully later.

Socioeconomics

Objectives

Socioeconomic factors contribute significantly to whether or not farmers will adopt modified management practices. The socioeconomic portion of MSEA research incorporates the following objectives:

- to evaluate the profitability of alternative farming systems;
- to determine the relationship between the use of agricultural chemicals and actual or perceived water quality;
- to determine potential economic and environmental effects of current and proposed agricultural policies and programs at the watershed and regional levels;
- to assess farmers' attitudes, perceptions, and awareness of water quality issues and of the effects of farming on water quality;
- to identify personal and social aids and barriers to adoption of farming systems that improve water quality;
- to assess the impacts of the MSEA program on farmers' attitudes and behavior regarding agricultural chemicals, alternative farming systems, and the activities and programs of state agricultural experiment stations; local conservation districts; USDA's Soil Conservation Service, Extension Service, and Economic Research Service; and other agencies.

Research and Analysis

All MSEA's will conduct evaluations of conventional and alternative farming systems to fulfill the socioeconomic objectives. Procedures and data used in these evaluations vary among the MSEA's because the systems differ in their suitability for economic and sociological analyses. Minnesota, for example, will use representative costs and returns, and Missouri and Ohio will use on-site costs and returns to develop enterprise and whole-farm budgets. Iowa will use both farm budgets and interviews to evaluate the potential acceptance of different farming practices. Common assumptions, however, will guide the assessment of farm budgets, allowing the profitability of farming systems to be compared across MSEA sites. The costs and risks associated with converting to alternative farming systems will also be investigated.

Several MSEA's will employ mathematical models to evaluate the farm-level profitability of selected farming systems. One such system—a chance-constrained model—will emphasize maximum farm income under different levels of water contamination. In another, a mathematical programming model is combined with cost and return budgets to evaluate the effects of crop yields, crop prices, and farm and resource conservation policies on the selection of farming systems. Of particular interest are policies that restrict the use of chemicals and policies that enhance planting flexibility by not penalizing farmers for using crop rotations and reducing chemically intensive farming practices.

Information about adoption of ground water protection practices will be collected from owner-operators in all MSEA areas. In order to compare attitudinal behaviors across MSEA's, similar factors will be examined. These include existing farming practices, chemical application rates, the basis for decisions about adopting technologies and techniques, institutional barriers to and facilitators of adopting new farming practices, attitudes about water quality problems, perceptions about environmental degradation associated with production agriculture, access to and use of information on environmental quality, the characteristics of owner-operators, and the characteristics of farming enterprises.

The application to entire regions of findings gathered from the limited number of MSEA sites—considered the most challenging of the socioeconomic objectives—is essential for policy analysis. Two approaches are being considered for the regional economic and environmental assessments of the farming systems.

The first method would combine economic and environmental information about the farming systems with data from the National Resources Inventory (NRI). NRI is a scientific survey of information about land use and land cover, soil type, soil erosion, and other land attributes collected from more than 800,000 sampling points throughout the 48 contiguous states. The method would involves three steps. First, the actual, or baseline, farming systems for the 1989–92 period would be identified for each Major Land Resource Area (MLRA) based on information about crop practices in the 1992 NRI. The impact of water quality on the baseline farming systems will be determined from MSEA research and other studies. Data about soil erosion, water quality, and economic impacts would then be aggregated across MLRA's, yielding a regional assessment of the baseline farming systems.

In step two, alternative farming systems would be specified for the NRI sampling points and, as in step one, soil erosion, water quality, and the economic effects of alternative farming systems would be estimated for each MLRA. In the third step, soil erosion, water quality and the economic effects of alternative and baseline farming systems would be compared.

The second method for achieving regional evaluation derives from three ideas: (1) using microresearch data to calibrate models that simulate environmental processes; (2) using these calibrated models with statistical sampling designs to generate data for a representative set of parameters (policy, climate, soil, chemical, and management) and summarizing these data for use in regional prediction; and (3) integrating economic and environmental models so they can be used to evaluate policy.

Technology Transfer

If the benefits of MSEA research are to carry, then it is important that research results be communicated to producers and others concerned with agriculture. To facilitate this transfer of technology USDA's Extension Service has earmarked funds to establish staff and programs in five states to disseminate information. An extension specialist, who serves on the MSEA project management team, will coordinate education activities among the five MSEA projects.

USDA's Soil Conservation Service (SCS) also designated an individual to serve on the advisory committee at each MSEA site. These people will advise on the practicality of research and the structure of findings to facilitate their use in field offices. In turn, appropriate representatives from the MSEA sites will attend SCS meetings to guide incorporation of research results into conservation management systems.

Each of the five states was required to submit a proposal for developing the educational component of the MSEA program. Common themes that emerged are discussed next.

- Establishment of an information base. Each state will establish an information base of research results for dissemination through brochures and field days.

- Dissemination of research results. The Extension Service and SCS will link the research effort to producers in two ways: (1) by participating in planning so research reflects practices that producers can really adopt, and (2) by coordinating the dissemination of research results to the producer and the public.

- Coordination with state projects and agencies. Efforts will include joint development of educational materials, publications, and programs, joint sponsorship of conferences, and joint training sessions.

The Ecology

Agricultural practices in the Midwest have dramatically altered the landscape during the past century, and land use modifications have significantly influenced the ecological processes and community structure of the agroecosystem. Habitat fragmentation, such as reduction in the size of forests and woodlands, has decreased or eliminated corridors for wildlife movement, nesting, and feeding in agricultural communities, resulting in increasingly isolated wildlife populations that are vulnerable to extinction. Modification of riparian zones along streams has been a cause of soil erosion from agricultural fields and stream banks and has increased siltation in streams, resulting in loss of benthic habitat, increased stream temperature, and decreased stream oxygen content.

Changes in land contour and vegetation mosaics have contributed to the movement of agricultural chemicals from the areas of application to nearby streams or aquifers. These chemicals can have a negative impact on the environment and, as noted previously, human health. Pesticides that can cause cancer, neurotoxicity, birth defects, and other reproductive defects have altered aquatic and terrestrial communities, frequently to the point where fish populations and wildlife species have been drastically reduced. Draining or filling wetlands to increase acreage for crop production has also reduced the ecosystem's capacity to process anthropogenic chemicals and nutrients, in addition to eliminating a vital habitat for many native plant and animal species.

Another element deserving consideration is the abundance of life below ground. Compared with aboveground ecology, little is known about subsurface ecology, particularly the effects of agriculture on the subsurface ecosystem. But knowledge of subsurface ecology is needed in order to take an integrated approach to the agricultural pollution problem.

Microbial life is found throughout the vadose zone into groundwater. Because subsurface organisms have the capability to degrade almost all compounds, they play a major role in biogeochemical cycling and in maintaining the integrity of the ecosystem. Also contributing to these processes are abiotic reactions and mechanisms. A major challenge is to determine the assimilative capacity of the subsurface in an agricultural environment (in other words, the ability of a particular environment to absorb or modify contamination).

MSEA goals for researching the effects of agriculture on the ecology are

- to determine the environmental benefits (on ground and surface water and related ecosystems) of those agricultural management systems proposed for best management practices;
- to identify measures that would prevent ecological and hydrologic degradation and would restore ecosystem functions at the watershed level; and
- to provide to the states diagnostic and predictive tools for implementing site-specific, watershed, and regional water quality management programs based on sound ecological and hydrological practices.

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Iowa MSEA

Project Goal

The goal of the Iowa MSEA project is to evaluate the effects of agricultural management systems on ground water quality in three regions of the State.

Site Descriptions

The Iowa MSEA centers on three major sites—one in the western area (deep loess soil), one in the central area (Des Moines Lobe or thick glacial till soil), and one in the northeastern area (thin glacial soil at Nashua). The sites are characteristic of 35 percent of the state in that the land is used primarily for corn or corn-soybean rotation. Small areas are native or seeded pasture or are cultivated with small grain or alfalfa.

Western Region
The western MSEA site is located in an area known for deep loess soil over rolling glacial till. The topography is characterized by narrow, gently sloping ridges, steep side slopes, and well-defined alluvial valleys. The upland soils exhibit a well-drained structure and a high water-holding capacity. Given the steep slopes, these soils under cultivation are vulnerable to erosion and large amounts of surface runoff. The strata above the Mississippian Aquifer are undifferentiated sandstone and shale. The structures of the soils and the strata provide a good opportunity to study the transport and fate of water and chemicals.

Des Moines Lobe
Approximately 20 percent of Iowa is covered with soil from the Clarion-Nicollet-Webster soil association. These soils are extensively cultivated because the topography is nearly level to gently rolling. The Clarion soils range from well drained and moderately permeable on the upland sites with a high water-holding capacity and high fertility level to poorly drained with moderate permeability. The parent material for these soils is glacial till, and they developed under prairie vegetation.

The Walnut Creek watershed, south of Ames, was chosen as a site for intensive study because it is representative of the Des Moines Lobe region and it couples directly with the Skunk River alluvium. The upper reaches of the watershed are intensively tile-drained with no defined surface flow patterns, while the areas along the stream exhibit defined surface flow patterns.

In the low-lying alluvial areas along the rivers, the soils are from loamy alluvium and are poorly drained and moderately permeable with a high clay content. Other soils are moderately well drained and moderately permeable and are neutral to slightly acid throughout the profile. Some of the soil series have a high clay content and tend to be neutral to acid with a high shrink-swell capacity. These soils require drainage because of their poor internal drainage characteristics.

The Mississippian Aquifer lies under the Des Moines Lobe area. In this area the Des Moines River Valley and the Skunk River Valley are discharge areas for the aquifer; the idealized flow would be through the glacial drift into the aquifer and then through the aquifer to the river valleys.

Nashua
The Nashua area ranges from level to gently rolling. The soils of the region, which are characteristic of 10 percent of the State, are formed from glacial loam till and have a high water-holding capacity with moderate to poor drainage. Underlying the area is the Silurian-Devonian Aquifer, which is characterized by carbonate and yields large quantities of water in some localities.

Water Quality
Shallow wells in all three regions show nitrate and pesticide infiltration. A 1988 assessment of the western site revealed median nitrate-nitrogen concentrations in water of 1.8 mg/L for wells up to 15 m deep and 1.3 mg/L for wells more than 15 m deep. Twenty-four percent of the wells less than 15 m deep had atrazine concentrations of 0.1–24 µg/L, with a median of 0.3 µg/L. Pesticide concentrations increased in the summer.

Water use and water quality in the Des Moines Lobe area are similar to those of the western region, with nitrates and pesticides detected in shallow wells. These substances were also found in the tile flow and runoff from agricultural fields, with nitrate in excess of 70 mg/L tile flow and 7.0 µg/L atrazine in some areas.

Studies begun in 1990 to determine the cropping histories of several fields are monitoring the tile flow, surface runoff, and transport of water and chemicals at the Walnut Creek watershed in the Des Moines Lobe. The researchers have established baselines of nitrates and pesticides in the soil and will analyze different soil map strategies. The till-hydrology site (a small station located near Boone, IA, in the Des Moines Lobe), which has been monitored for a number of years, was equipped with a "nest" of wells in 1990 to collect samples for pesticide analysis from the vadose zone.

Wells at the Nashua site are generally deeper and exhibit much lower concentrations of nitrates and pesticides than do those of the other two regions. However, water from

shallow wells in this northeastern portion of the State have the same characteristics as well water of the other two regions.

Project Objectives

The Iowa MSEA has five objectives.

1. Quantify the physical, chemical, and biological factors that affect the transport and fate of agricultural chemicals.

   The project will focus on the five most commonly used pesticides in Iowa: atrazine, alachlor, cyanazine, metribuzin, and metolachlor. Researchers will measure the movement of these pesticides and their major degradation products in carbon-14 pesticide-treated, undisturbed soil columns. They will also assess the persistence and degradation of pesticides and their degradation products in saturated and unsaturated soils. They will measure the influence of surface conditions from different farming practices on the volatilization of atrazine and alachlor. And they will study the microbial degradation of pesticides and the chemical processes in soils with varying amounts of organic matter and differing surface tillage.

2. Determine the effects of crop, tillage, and chemical management practices on the quality of surface runoff, subsurface drainage, and ground water recharge.

   Achieving this objective requires quantifying the effects of different tillage practices on the efficiency of nitrogen fertilizer uptake and evaluating the movement of nitrogen-15 under different soil and tillage conditions. How tillage and crop rotation affect the movement of nitrogen and herbicides in a glacial till and a loess soil will be evaluated, as will the impact of adopting modified farming practices on the hydrological balance and the movement of agricultural chemicals.

   Studies are being conducted on a glacial till soil to determine the relationship between the topography and the movement of agricultural chemicals and nitrates. A pothole is being studied to determine the patterns of movement within a field and the transformations of pesticides and nitrates within a landscape. Fields where modified farming practices are used (for example, banded pesticides with ridge-till, split application of nitrogen fertilizer, and no-till ridge-till with altered chemical management) will be compared with fields farmed with conventional practices.

3. Integrate information in meeting objectives 1 and 2 with data about soil, atmospheric, geologic, and hydrologic processes to assess the impact of these factors on water quality.

   This requires the use of root zone models to test how changes in the farming system affect nitrogen and pesticides in the soil and the vadose zone. The origin and flows of water will be mapped in order to track the movement of chemicals to ground water. The impact of changing farming systems on the quality of runoff, soil, solution, and ground water will be assessed.

4. Evaluate the socioeconomic effects of current and newly developed management practices.

   Based on research results, farmers in the region will receive recommendations and technical assistance to adopt new farm management systems. The socioeconomic effects of these strategies will be monitored and the results conveyed to policymakers.

5. Understand the ecological effects of agrichemicals, distinguishing them from the impacts of other agricultural practices. Evaluate alternative management practices for their long-term effectiveness in preventing ecological degradation, in contributing to restoration of the ecosystem, and in maintaining agricultural productivity.

   Diagnostic and predictive tools will be developed for assessing agricultural management practices and implementing those which minimize negative effects on the landscape, the watershed, and the region.

Research Design

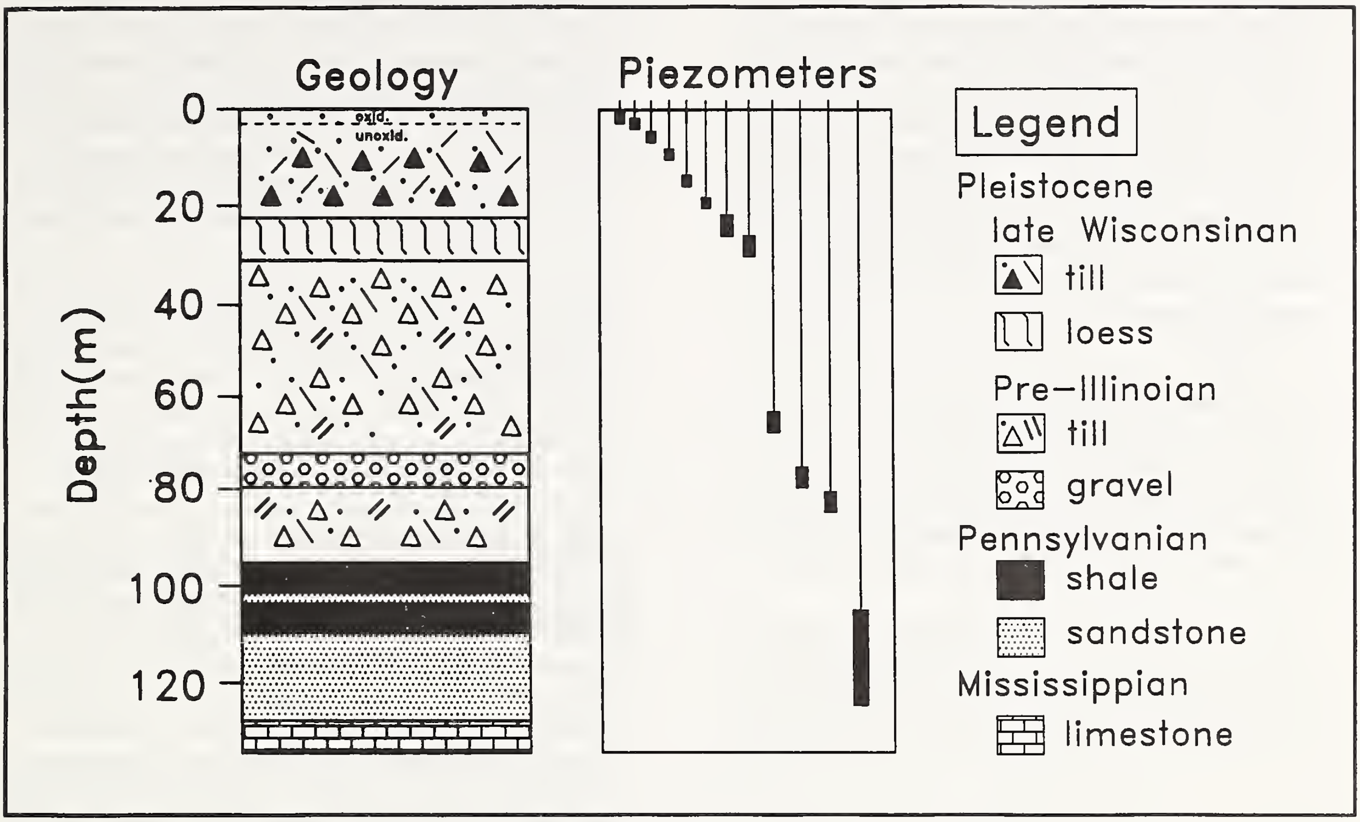
Relationships Among the Sites

The three sites share the same experimental protocols and common farming systems, while variations in the soil and climate allow comparisons of many different process models. The component studies being conducted at each site include chemical and microbial degradation, preferential flow modeling and measurement, infiltration measurements, nitrogen transformations, changes in organic matter in different tillage practices, and evaluation of the soil water balance under different tillage regimes. Quantitative comparisons will be made among sites, using experimental data and computer model simulations. Several component models are being developed, including microbial degradation, chemical transformation, solute and heat flow, soil water balance, nitrogen transformation and balance, and solute movement and transformation in the vadose zone.

Deep Loess Research Station

The Deep Loess Research Station in the western region has four watershed agricultural sites. Two of the four watersheds operate with a cropping practice of continuous corn, with disking as the tillage practice; another watershed uses continuous corn with ridge tillage; and the fourth watershed operates as a double-spaced parallel-terrace system with

Figure 6. The Till-hydrology Site, IA: Placement of wells and flow of ground water in the geologic strata over the Mississippian Aquifer



underground pipe outlets and ridge tillage. This variety allows comparison of runoff and water movement in three crop management systems.

As a new crop management strategy, a strip-cropping system was initiated in the parallel terrace in 1993. Detailed studies will be conducted on the movement and persistence of atrazine and nitrate in the soil profile. The deep soils enable analysis of the rates of movements and of chemical transformations, and deep wells will be installed to examine movements within the root and vadose zones. Within each watershed the hydrologic balance will be measured to examine the patterns of water and solute movement in different farming systems.

Each watershed contains a weir system equipped to collect base flow and runoff samples for pesticide and nitrate analysis. Wells in each watershed will be used to measure the height of the water table and to collect water quality samples each month.

In the ridge tillage watershed, deep wells were installed in 1991 to sample the movement of water and volatilized pesticides throughout the profile in different depths above the glacial till. These samples will be related to microbial activity measured in the root and vadose zones.

Each pair of watersheds shares a complete meteorological station, which operates year round. A wet-dry precipitation sampler collects samples for every rain event above 2.5 mm.

Des Moines Lobe Area

Till-hydrology site. Research at the till-hydrology site focuses on measuring the movement of chemicals and the age of water at various depths to 150 m (fig. 6). Cropping systems include continuous corn and a corn-soybean rotation with documented nitrogen and pesticide applications.

Deep wells are positioned to provide samples from each geological unit above the Mississippian Aquifer. Collected monthly, samples are analyzed for pesticide and nitrate concentrations. Additional samples collected for hydrogen-3 and oxygen-18 concentrations determine the age of the water from the various geological units.

A series of continuous corn conventional tillage plots and no-till plots receive nitrogen fertilizer at different rates and times to assess the effect of split applications on surface and ground water quality. Piezometers in each plot quantify the movement and quality of water samples. A sump pump system measures the tile flow from each plot, and runoff collected from two of the plots is used to quantify the amount and quality of water lost from the surface.

Walnut Creek watershed. Walnut Creek represents a typical watershed in the Des Moines Lobe. Farming systems that are candidates for use include a corn-soybean rotation, continuous corn, and corn-soybean-grain-legume rotation. The cropping systems selected for study depend upon the farmers' willingness to alter farming practices. A narrow strip-cropping system will replace some rotations. In one field, conventional tillage will be replaced with ridge-till that includes banded pesticides and split nitrogen applications. Nitrogen fertilizers, chemicals, and tillage practices will be varied within the corn-soybean rotation. Each variation in farming practices will be documented to assess any related changes.

Study fields in the Walnut Creek watershed typify various portions of the landscape. These fields will be monitored for surface runoff, tile flow, and ground water quality. Atmospheric variables and soil samples will be collected to determine the concentrations and degradation products of pesticides and nitrates in different portions of the landscape and the pesticide amounts in the root zone.

In order to track changes in water quality resulting from changes in farming systems, three stream sampling systems will continually measure stream height and temperature, rainfall, sediment, and water quality using a programmable data acquisition system. Nitrogen transformations will be studied by analyzing anaerobic and aerobic conditions in the streambed and the flow of water down the stream and laterally from the surrounding fields.

A series of 24 tipping-bucket rain gauges will measure the intensity of rainfall throughout the watershed at 5-min intervals. After each rainfall, a wet-dry precipitation sampler will collect samples for pesticide and nitrate analysis. Rainfall will also be collected from canopy washoff to assess pesticide and nitrate concentrations on leaves of plants.

A 320-ha subbasin is instrumented to measure the total surface runoff and tile flow from a collection of fields. Wells up to 10 m deep around the perimeter of the subbasin enable monthly measurements of the height of the water table and the water quality. In addition, soil samples to a depth of 1.5 m will be taken eight times a year to measure pesticide concentrations.

A large pothole was instrumented to measure the movement of water and solute concentrations from the surrounding land. Transects of piezometers placed across the pothole measure the pattern of water movement to the pothole and the amount of lateral flow. A tile drain was placed through the center of the pothole, and outflow from the tile is monitored continually; water quality is sampled during events and at routine intervals. Measurements made of microbial populations across the pothole will be related to denitrification and pesticide degradation. Soil samples are collected throughout the year to quantify concentrations of parent compounds and metabolites.

Soil water balance is measured with neutron access tubes placed through and around the pothole and with a complete Bowen ratio setup, which quantifies the energy exchange process and the evapotranspiration rate in the field. These data are compared with those from other fields where surface features were altered by farming practices such as no-till or ridge-till.

In fiscal year 1992, the first year of research, EPA completed an assessment of the ground water, surface water, and ecology of Walnut Creek, along with an analysis of its relationship to the western Corn Belt ecoregion. As a result of the assessment, a plan developed in cooperation with USDA and the landowners will identify management practices (such as buffer strips, restored wetlands, winter cover crops, and hedgerows) that are most beneficial to the entire ecosystem and that maintain agricultural productivity. These practices will be implemented, where possible, and monitored to assess effectiveness and change.

Nashua Area

The three crop rotations at the Nashua site—continuous corn, corn-soybean, and soybean-corn—are grown under four different tillage practices—ridge-till, no-till, moldboard plow, and chisel plow-disk. Alachlor and atrazine have been applied each year to the continuous corn crop, along with nitrogen, phosphorus, and potassium. Alachlor and metribuzin, along with nitrogen, phosphorus, and potassium have been applied to the corn-soybean rotations. No changes in the systems are planned for the first 2 years of the project, but after that, the amount and interval of nitrogen applications will probably change.

Experimental plots consist of 36 0.4-ha plots and a series of bedrock wells at various depths in an area adjacent to the plots. Monthly samples from the wells are measured for hydraulic gradient and water quality.

Installed in the center of each plot is a tile line intercepted by a sump pump system. Each tile line is measured for flow rate, and water samples are periodically collected at specific flow volumes. Four plots have an H-flume to measure the surface runoff and automatic samplers to collect samples for surface water quality. Two piezometers installed at two depths in each plot measure hydraulic gradient within the plot. Soil samples are collected eight times a year to a depth of 1.2 m for pesticide and nitrate concentrations.

Nashua has a complete meteorological station including a wet-dry precipitation sampler, which collects samples from rainfall events over 2.5 mm. These samples are analyzed for the pesticide and nitrate concentrations.

Computer Models
The following computer models will be incorporated into the research to display the relationships between agricultural practices and water quality specified in the project goal and objectives: (1) SOILSIM, which describes processes within the root zone; (2) Root-Zone Water Quality Model, a one-dimensional model that will be expanded to a two-dimensional model for the MSEA project; (3) Pesticide Root-Zone Model (PRZM); (4) Ground-water Loading Effects of Agricultural Management Systems (GLEAMS); and (5) Precipitation-Runoff Modeling System, which is being developed by the Geological Survey to predict changes in water quality in the Walnut Creek watershed. In addition, micro- and macroeconomic models will be developed for evaluation of alternative farming practices on this watershed.

Research Products

Research products will consist of research reports, mathematical models, articles in scientific and popular periodicals, press releases, annual reports documenting project progress and findings, and quarterly newsletters of research and intermediate results for the farmers and landowners of the Walnut Creek watershed.

The general categories of the expected research products are listed following:

- evaluation of the geological structure of the glacial till of the Des Moines Lobe and the impact of this structure on the rate of water movement to the Mississippian Aquifer;
- in the Walnut Creek watershed, evaluation of a ground water hydrology model that incorporates herbicide movement;
- evaluation of chemical transformation processes on a loess and a glacial till soil under different tillage practices;
- evaluation of the microbial degradation of atrazine and alachlor in the surface and subsurface of loess and glacial till soils;
- development of mathematical models of the chemical transformations in various tillage systems;
- evaluation of the nitrogen balance and nitrogen movement in different soils and farming systems;
- evaluation of methods used to measure herbicide metabolites in soil and water;
- evaluation of the rates of herbicide volatilization in different farming systems;
- development of improved techniques for nitrogen management in glacial till and loess soils;
- development of methods for the chemical trapping of volatilized pesticides;
- development of preferential flow models for glacial till soils;
- evaluation of the impact of soil cracking on water infiltration and chemical movement;
- development and evaluation of economic models that assess the impact of changing chemical management;
- evaluation of the effect of changing technology on the adoption of new practices; and
- evaluation of the impact of changing farming practices on water and chemical movement in an agricultural landscape.

Minnesota Northern Corn Belt Sand Plain MSEA

Project Goal

The goal of the Northern Corn Belt Sand Plain project is to evaluate the impact of a ridge-tillage corn-soybean rotation on ground water quality in representative sand plains within four geographic settings.

Site Description

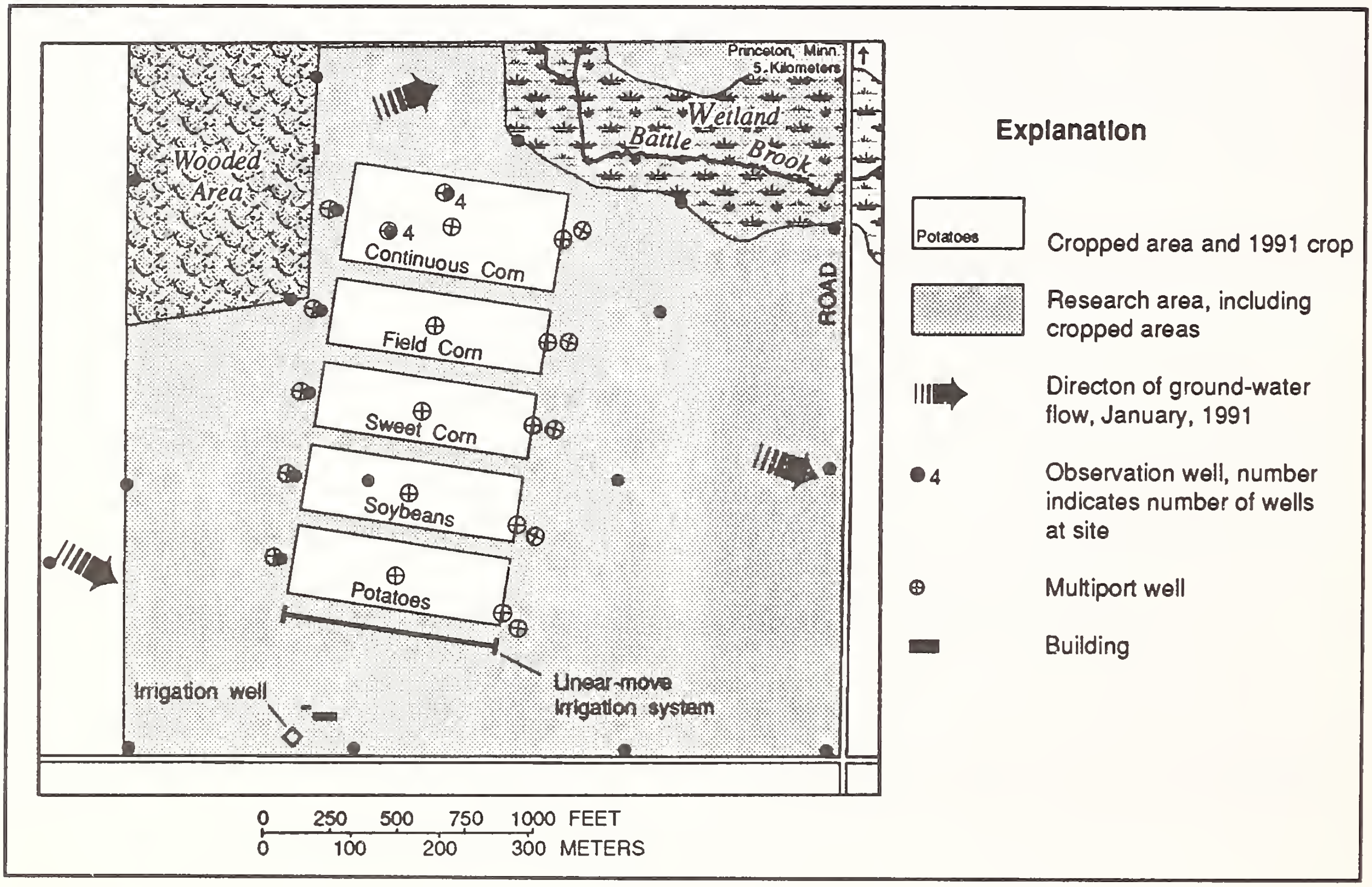
The Northern Corn Belt Sand Plain MSEA sites comprise the Anoka Sand Plain in Minnesota, the Wisconsin River Sand Plains in Wisconsin, the Oakes Irrigation Research Site in North Dakota, and the Big Sioux Aquifer area in South Dakota (fig. 7).

Pesticide surveys, field-scale experiments, and regional studies indicate that the sand plain hydrological setting is one of the most vulnerable to contamination. Contamination from point and nonpoint sources, including farms, septic systems, landfills, cities and towns, and road de-icing salts, has been found in Minnesota, Nebraska, Iowa, Wisconsin, and Illinois; all of these states include significant areas of sand plain aquifers. The results of this portion of the MSEA study will be transferable to other sand plain areas in the Midwest and elsewhere.

Anoka Sand Plain (Minnesota)
The Anoka Sand Plain Aquifer covers about 4,400 km^2 and is one of the largest surficial aquifers in Minnesota. It consists primarily of gray, calcareous outwash like that derived from the Des Moines Lobe and is typical of sand plains throughout the Corn Belt.

Like other sand plains, the Anoka Sand Plain is characterized by the extreme values of many of its hydrogeological factors, which make it very sensitive to land surface practices. These factors include high hydraulic conductivity of the soil and the saturated and unsaturated zones; shallow depth to the water table; flat topography and low runoff; high rates of recharge and ground water seepage; high baseflow or seepage to surface water bodies; low organic carbon; low sorption to the aquifer matrix; and large annual temperature fluctuations.

Figure 7. Plot layout at the Anoka Sand Plain site



The principal research site is about 5 km southwest of Princeton, MN, and about 80 km northwest of Minneapolis and St. Paul. Material in the unsaturated and saturated zones generally consists of fine-to-medium sand and medium-to-coarse sand, respectively. Core holes drilled on the site perimeter revealed a silty layer 5–35 cm thick and between 1.2 and 2.7 m beneath the land surface in the unsaturated zone. Depth to the water table is approximately 3.6 m. The unsaturated zone is 5–12 m thick. Saturated hydraulic conductivities are about 0.04 cm/sec, and ground water velocities are about 5 cm/day. Clay-rich till of lower permeability underlies the surficial aquifer.

Ground water flow is generally from west to east through the site. Streams form natural hydrologic boundaries around the site. Ground water discharges primarily to Battle Brook and an associated wetland located in the northeast corner of the site. The ground water flow gradient is about 1 m/km and the ground water recharge rate is about 20 cm/yr. The likelihood of previous upgradient agricultural chemical use at the site is minimal.

Water quality. Surface and ground water at the Princeton site are of the calcium bicarbonate type. Ground water samples were collected in April 1991 from 14 wells located both within and around the perimeter of the site. These samples were taken before application of agricultural chemicals and had nitrate-nitrogen concentrations between 0.02 and 19.92 mg/L, with a mean concentration of 8.22 mg/L. Concentrations of chloride in the 14 wells were between 0.56 and 25.70 mg/L, with a mean concentration of 11.43 mg/L. Sulfate concentrations ranged from 0.90 to 43.30 mg/L, with a mean of 9.45 mg/L. Values of pH ranged from 5.90 to 8.30 with a mean of 7.29. Specific conductivity ranged from 142 to 490 microsiemens/cm at 25 °C and had a mean of 279 microsiemens/cm. Concentrations of dissolved oxygen were between 3.62 and 10.5 ppm, with an average of 7.12 ppm. Alkalinity ranged from 16 to 179 mg/L as calcium carbonate and averaged 95 mg/L.

Immunoassay tests for the triazine herbicides and alachlor were performed as a preliminary qualitative screening tool before quantitative gas chromatograph-mass spectrometer analysis. Of the 14 wells sampled, three had positive detections for triazines and one had a positive detection for alachlor. A sample collected from Battle Brook tested positive for triazines and alachlor.

Soil. Soils on the Anoka Sand Plain consist primarily of the Zimmermann-Isanti-Lino association. These soils occur on broad, undulating outwash plains across east central Minnesota and were formed in fine-textured sandy sediments. All three soils have a surface layer of loamy fine sand and a subsurface of fine sand; distinctions between the types are related to soil drainage, which varies with their position in the landscape and the depth of the water table.

The Zimmermann soil occurs on broad, undulating uplands and narrow escarpments and is excessively drained. Native vegetation was mixed oak forest. The Lino series, which is poorly drained, is found on small flats, depressions, and drainage ways. Native vegetation was mixed hardwood forest. The Isanti soil is found in depressions and on low-lying flats and is very poorly drained. The soil has marsh vegetation. All three soils are slightly to strongly acid (5.1–6.0 surface pH), are highly permeable (15–50 cm/hr), and have very low water-holding capacities (less than 0.1 cm of available water per cm of soil). Wetness associated with the high water table is the major restriction affecting agricultural land uses.

Weather and climate. Based on records from 1910–70, precipitation for the area averages 70 cm/yr (balanced by runoff of 15 cm/yr and evapotranspiration of 55 cm/yr); about 20 of the 70 cm circulates through the surficial aquifer system with negligible long-term changes in storage. The mean monthly precipitation in the Anoka Sand Plain ranges from 20 cm in January to 125 cm in June. Evapotranspiration is greatest in June–August. Ground water discharge to rivers ranges from 2 to 5 cm/yr. Average daily minimum temperatures range from −18 °C in January to 15 °C in July; average daily maximum temperatures range from −7 °C in January to 28 °C in July.

Wisconsin River Sand Plains (Wisconsin Satellite)
The soils are deep, permeable sands that are farmed intensively. Extensive detections of atrazine in the ground water along the lower Wisconsin River explain the intense research and outreach activities related to agrichemical contamination. A widespread program of sampling domestic wells is under way by state agencies, as well as research and education efforts.

Oakes Irrigation Research Site (North Dakota Satellite)
The aquifer system in the area consists of medium sand to gravel. There is till at approximately 0.2 m. The depth to the surface of the aquifer is approximately 3 m. Annual precipitation averages 45 cm. Runoff is generally 2 cm or less, and 23 cm of water circulates through the aquifer at the irrigation site.

Big Sioux Aquifer (South Dakota Satellite)
The aquifer is shallow, with an average thickness of 3 m and the water table within 4.5 m of the surface. The entire drainage basin for the aquifer is approximately 3,000 km^2 and covers much of eastern South Dakota. Annual precipitation for this area is 53 cm (with 8 cm of runoff and 45 cm of evapotranspiration), and about 10 cm of water circulates through the aquifer system.

Project Objectives

The research objectives of the project are as follows:

1. To investigate the impact of ridge-till practices in a corn and soybean cropping system on ground water quality and on the rate of transport of nitrate-nitrogen, atrazine, alachlor, and metribuzin in the saturated and unsaturated zones;

2. To determine the effects of nitrogen management by soil tests and plant analysis;

3. To characterize ground water flow through the sand and gravel aquifers and correlate the characteristics of the aquifers to the transport and storage of agrichemicals; and

4. To determine the relationship between the rates of ground water recharge and the rates of agricultural chemical loading to ground water.

Research Design

The research will focus on the effects of the following three cropping systems: (1) a field corn-soybean rotation utilizing ridge-till to reduce pesticide use; (2) a chemically intensive, ridge-till, sweet corn-potato rotation in wide use in the northern sand plains, and (3) continuous corn using conventional tillage and conventional pesticide and fertilizer application procedures.

All three systems will be used at the Anoka Sand Plain site near Princeton and the field corn-soybean rotation with ridge till will be used at the satellite locations in Wisconsin, North Dakota, and South Dakota. Through the use of the corn-soybean rotation with ridge-till in all four sand plain locations, it will be possible to identify the effects of nitrate and herbicides on ground water in varying climatic settings. Data collected from the Princeton site will be plotted to show the spatial distribution of agrichemicals in the saturated and unsaturated zones. These data will then be compared with similar data collected at the satellite sites in North Dakota, South Dakota, and Wisconsin.

Statistical methods, such as logistic regression analysis and nonparametric analysis, will be used to identify regional patterns of atrazine in ground water. Deterministic computer models such as CREAMS, LEACHM, GLEAMS, PRZM, AGNPS, MODFLOW, and VS2D will simulate the processes that move and transform pesticides.

A geographic information systems (GIS) data base will manage, display, analyze, and spatially map factors such as the rate of atrazine application, the depth of water, soil type, soil pH, aquifer thickness, prevailing wind pattern, and precipitation rate.

The Minnesota Pollution Control Agency (MPCA) will conduct research at the Princeton site and other Anoka Sand Plain fields with a corn-soybean rotation to evaluate this system as a best management practice for reducing nonpoint-source pollution and achieving water quality goals within the surficial sand plain aquifer of east central Minnesota. Specific MPCA objectives are to (1) increase knowledge about the fate and transport of solutes within this hydrological setting and (2) assess methods to evaluate chemical transformations including nitrate reduction and movement of solutes.

Several techniques will be used to predict the existence and location of preferential flow paths for herbicides and nitrate. Soil variability will be determined to a depth of 3 m at selected sites. Special attention will be paid to within-pit variability of soils and features that may cause contaminant behavior, such as grain coatings, biopores, complex sediment layering, particle size, and surface charge characteristics. Infiltrometers will be used to measure the hydraulic properties of soil near saturation. A three-dimensional map of soil characteristics will be produced with ground-penetrating radar.

Evapotranspiration and photosynthesis will be measured with a portable chamber. Microclimate data will also be collected for use in predicting evapotranspiration and assessing the development of cropping and management systems that promote the efficiency of irrigation and that minimize agrichemical movement.

Farm Management Systems

Ridge-till field corn-soybean rotation. The field corn-soybean rotation uses a less-than-full-width ridge-till system in which both crops are planted each year. The ridge-till system reduces the use of herbicides and fertilizer since applications are confined to the immediate vicinity of the corn; weeds between rows are controlled by the residue, which suppresses weed growth, and by subsequent cultivation.

The rate of fertilization will depend on soil tests. The pesticides atrazine, alachlor, and metribuzin will be applied according to recommendations contained in WEEDIR or a similar guide and insecticides will be applied according to INSREC or a similar guide. Irrigation will be done according to predictions of a state-of-the-science irrigation scheduling system.

A cover crop planted in early fall and winter-killed will be used following the soybean crop to control wind erosion and minimize nitrate movement during the winter. Usefulness of the corn crop residue for erosion control and nitrate immobilization will be determined.

Sweet corn-potato rotation. The sweet corn-potato rotation uses full-width tillage consisting of disk, chisel, and field cultivators. This tillage system will help retain crop residues

on or near the soil surface to control wind erosion. Sweet corn residues incorporated immediately after harvest in August will have a green manuring action. A legume-nonlegume mixture that is not winter hardy will be used as a cover crop.

Potato harvest is early and facilitated by a vine burndown to allow planting a cover crop that will scavenge nitrates, reduce soil erosion, and reduce weed competition. In the spring the area is disked before planting sweet corn. Two cultivations are used to control weeds during the season. Following corn harvest, the area is disked and a cover crop is planted. In the spring the area is disked in preparation for planting potatoes.

Fertilization will consist of banded applications at a rate recommended by soil testing. A potato vine killer may be needed at early harvest to help establish the cover crop. Other pesticide use and irrigation practices will follow the guidelines mentioned previously for the field corn-soybean rotation.

Continuous corn. The continuous corn system is a conventional system with the exception that excessive irrigation may be needed to ensure movement of the applied chemicals to ground water. This system is established at the Princeton site in the ground water recharge area of the Geological Survey.

Tillage is with full-width chisel plow. The rate of fertilization is that recommended by the University of Minnesota, and fertigation is used as needed. Atrazine and alachlor are used according to WEEDIR recommendations and insecticides, according to INSREC recommendations.

Data Collection

Soil samples taken from the Princeton site will be used to determine the extent of herbicide and nitrate movement in the unsaturated zone in the ridge-till system. Two soil cores will be collected per plot before pesticide application and at intervals of 2, 5, 11, and 18 weeks following pesticide application at depth increments varying from 0–15 cm to 213–244 cm. If neither herbicides nor nitrates are detected in samples taken postharvest, preapplication (spring) samples will not be taken for analyses. Because coring may alter the hydraulic properties of the soil around the opening, bentonite will be used to backfill and seal each borehole.

The effect of the farming systems on the quality of the ground water will be determined by analyzing water samples collected from multiport samplers installed upgradient, within, and downgradient of each plot. About 30 multiport samplers will be installed. Each of these will contain six sampling ports installed 0.5 m deep in the saturated zone so the distribution of agrichemical concentrations can be plotted in three dimensions.

Water samples will also be collected from ground water observation wells, precipitation, and Battle Brook adjacent to the site (fig. 7). Samples collected from wells in off-site locations will help determine the comparative concentrations of agrichemicals in these areas.

Immunoassay tests will screen for the presence of herbicides in ground water, and depending on the results, quantitative laboratory analyses will be conducted on selected samples. At each monitoring point, samples will be taken four times a year to quantify agricultural chemical concentrations following field applications and recharge events. The frequency of sampling will be adjusted based on the results of chemical analyses and on other research taking place at the site. The collection of soil and water samples will follow protocols outlined by the MSEA quality assurance-quality control subcommittee.

The three primary agricultural chemicals being analyzed in water are atrazine, alachlor, and nitrate. Concentrations of the pesticides metribuzin, metolachlor, turbufos, and phorate in water will also be analyzed, if they are applied to crops. In addition, analyses will be done for several degradation products of atrazine (desethylatrazine and deisopropylatrazine) and alachlor (chloroalachlor and hydroxyalachlor).

Many processes will be evaluated that affect the fate and transport of agricultural chemicals in the atmosphere, soil root zone, unsaturated zone, saturated zone, and surface water. These processes include volatilization, atmospheric transport and deposition, plant uptake and bioaccumulation, mass transport and biodegradation, and the effects of macropore flow.

It is anticipated that the ridge-till farming systems will have less of a negative impact on ground water quality than traditional farming practices, although ridge tillage will still have a noticeable effect on the adjacent wetland and Battle Brook at the Princeton site. It is hypothesized that with ridge tillage, agricultural chemicals will not move so deeply into the unsaturated zone. It is further hypothesized that the ridge-till systems will reduce concentrations of pesticides in ground water about 50 percent and reduce the frequency of their detection, when compared with the conventional system. Concentrations of atrazine in ground water downgradient of the ridge-tillage plots will probably measure less than about 0.2 µ/L, with detections in about 10 percent of the samples, and concentrations of alachlor will be less than about 0.2 µ/L, with detections in about 5 percent of the samples. Concentrations of nitrate in ground water downgradient of the ridge-tillage plots should be below about 10 mg/L.

Research Products

Expected research results from the Minnesota MSEA project include (1) development of agricultural systems that reduce the movement of agricultural chemicals to ground water, (2) improved knowledge of the processes and factors that affect the movement of agricultural chemicals to ground water, (3) establishment of a data base that relates farming systems, hydrogeological factors, and water quality in varying climatic settings, and (4) educational materials for farmers and the public reporting the socioeconomic impacts of instituting and using a ridge-tillage system, compared with a conventional farming system.

Articles and reports will document the preliminary results of soil and water sampling conducted after the first year of study, describe the effects of ridge-tillage practices on water quality, and report ongoing research results.

Missouri MSEA

Project Goal

The goal of the Missouri MSEA project is to increase the knowledge needed to design and evaluate farming systems, educational programs, and public policies to reduce agricultural contamination of ground and surface water.

Site Description

The Missouri MSEA is located in the Goodwater Creek watershed, an agricultural area in the north central part of the state near the town of Centralia. A unique feature of the site is that it lies within a claypan soil region. Claypan soils of the Midwest prairie are problem soils. A clay sublayer, beginning at a depth of 15–30 cm, restricts air and water movement and retards root development. The upper horizons are usually low in natural fertility and are often acidic unless corrective treatments are made. The total area of Midwestern claypan soils is about 4 million ha. The principal areas are in Missouri, Illinois, and Kansas. Secondary areas, where the soils are sufficiently like a claypan that claypan management practices apply, occur in Oklahoma, Indiana, and Ohio.

Nitrate and pesticide contamination of surface and ground water in the Goodwater Creek watershed and surrounding areas is a concern for several reasons. First, droughty periods during the crop growing season can cause the claypan to shrink and the subsoil to fracture, resulting in high water flow through fracture macropores during recharge periods. Second, hydrologic conditions indicate that Goodwater Creek is a recharge source for the major regional aquifer. Third, Goodwater Creek flows into the Salt River which in turn empties into Mark Twain Reservoir, a public water supply and recreation area. Fourth, nitrate concentrations have been found to exceed the maximum contaminate level found in well samples near the watershed.

Much of the experimental research on alternative cropping systems in Missouri has focused on soil fertility. Knowledge is limited about how specific farming systems affect surface and ground water quality and the processes governing the movement of nitrogen and pesticides to ground water in claypan soils. It is hoped the Missouri MSEA project will improve the knowledge base.

Geology

The Goodwater Creek watersned is in the physiographic province of the dissected till plains, which includes significant portions of Kansas, Nebraska, Iowa, and Missouri. The dissected till plains were formed by pre-Illinoian glaciers; the area has since been subjected to considerable weathering and stream dissection. The glacial drift has been mantled by Illinoian and Wisconsin loess. Bedrock formations dip gently toward northwest Missouri and southwest Iowa.

Glacial drift in the Goodwater Creek watershed is underlaid by three different bedrock units. Pennsylvanian shales lie under most of the area. The northeast portion is underlaid by low-permeability Pennsylvanian limestone, and in the downstream sections of the creek the alluvium is in direct contact with the Mississippian Age Burlington limestone.

The unsaturated zone occurs in the loess and the upper till member of the McCredie Formation. As previously mentioned, there is well-developed claypan that begins about 15–30 cm from the soil surface. This claypan is extremely important to the hydrology of the watershed. The claypan is an argillic horizon, which is low in permeability. This low permeability leads to significant ponding and subsequent lateral flow over the claypan, often reaching the surface as side-slope seeps. During dry periods, the claypan develops desiccation cracks, which can lead to enhanced infiltration during subsequent rainfall events.

The depth to the water table in 1990 varied from 0.5 m to 4.8 m below the land surface. Water-level data collected between 1970 and 1985 indicate the water table drops by 1.5–3.0 m seasonally.

Three aquifers lie beneath the Goodwater Creek watershed. From deep to shallow, they are the Cambrian-Ordovician Aquifer, the Mississippian Aquifer, and the Glacial Drift Aquifer.

The Cambrian-Ordovician Aquifer is the most important regional aquifer in the area. It is composed of more than 300 m of Upper Cambrian to Middle Ordovician limestones, dolomites, and sandstones. Because of its productivity, it is the aquifer most often used for public water supply wells and irrigation wells. The Cambrian-Ordovician Aquifer is separated from the Mississippian Aquifer by a confining unit composed of the Upper Ordovician to Upper Devonian shales and limestones. Prior to pumping, water levels in the Cambrian-Ordovician Aquifer were generally 30 m lower than water levels in the Glacial Drift and Mississippian Aquifers.

Two flow systems occur in the Cambrian-Ordovician Aquifer. The northern flow system carries saline ground water and is diverted around the southern fresh water system. This very important fresh water system is maintained by recharge in areas where the overlying confining units are thin or absent, possibly including the downstream reaches of Goodwater Creek where the alluvium is in direct contact with the Mississippian Aquifer.

The Mississippian Aquifer is composed primarily of the Burlington and Keokuk limestones and is less productive than the deeper Cambrian-Ordovician Aquifer. It is extremely important in terms of recharging the Cambrian-Ordovician Aquifer. In general, the flow pattern is similar to that of the Cambrian-Ordovician Aquifer. The Mississippian Aquifer is confined by the Pennsylvanian shales and limestones. The confining unit is absent in the northern part of the watershed where the alluvium of Goodwater Creek is in contact with the Mississippian Aquifer.

The Glacial Drift Aquifer is perhaps best classified as a semiconfined aquifer, with the claypan acting as the confining layer. Recharge through the claypan does occur, but the aquifer responds to barometric changes in a fashion similar to confined aquifers. As previously discussed, there are probably seasonal variations in the permeability of the claypan due to the shrinking and swelling of the clay minerals in the claypan. When the water table is high, the loess is part of the aquifer; when the water table is low, the aquifer is composed only of the glacial till. The till is largely composed of silty clay with occasional sand lenses. The 6,730-ha watershed contains 38 domestic wells.

Soil

The Goodwater Creek watershed consists of silt loam soils predominantly from the Putnam-Mexico soil association. These soils contain a claypan horizon that impedes drainage in the spring and restricts available water storage. The soils were derived from Wisconsin loess, which varies from a depth of 0 at the creek bottoms to about 3 m at the ridge tops. The area is level to gently sloping.

These soils formed under native vegetation consisting mostly of tall grasses. A narrow band of forest is on the lower slopes and next to the drainageways. A typical landscape consists of broad cultivated fields on nearly level uplands, with pasture and forest on the drainageways and steeper slopes.

The soils in the area comprise the Armstrong silt loam, Leonard silt loam, Mexico silt loam, Putnam silt loam, Adco silt loam, and Chauncey silt loam. Armstrong silt loam is a deep, moderately well-drained to somewhat poorly drained soil formed in loess and glacial till on side slopes. It has a loam surface soil overlying a slowly permeable clay loam subsoil. Leonard silt loam is a deep, somewhat poorly drained soil formed in loess and glacial till on side slopes. It has a silt loam surface soil overlying a slowly permeable silty clay subsoil. Mexico silt loam is a somewhat poorly drained soil formed in loess on broad divides. It has a silt loam surface soil overlying a very slowly permeable silty clay subsoil. Putnam silt loam is a poorly drained, nearly level upland soil formed in loess. It has a silt loam surface soil overlying a very slowly permeable silty clay subsoil. Adco silt loam consists of very deep, somewhat poorly drained, slowly permeable soils on uplands and high stream banks. The Chauncey soil is poorly drained and has a surface texture of silt loam, while the slowly permeable subsoil has a silty clay texture. The landscape for the entire region is level to gently sloping, with grades ranging from 0 to 9 percent.

Weather and Climate

The temperature varies from a mean low of −4 °C in January to a mean high of 24 °C in July. Mean precipitation ranges from a low of about 2 cm in January to a high of slightly over 10 cm in May, while pan evaporation reaches its highest level of about 20 cm in July. The ratio of pan evaporation to rainfall indicates that moisture deficits are likely to occur during the growing season.

Hydrology

The topography of the watershed is nearly level, but the natural drainage system is well developed. Goodwater Creek rises on the southwest side of Centralia and travels nearly straight north for approximately 13 km. It then turns east and travels approximately 7.5 km to the weir at the outlet of the watershed. An unnamed tributary rises on the northeast edge of Centralia. This tributary approximately parallels Goodwater Creek in its northward path, merging with the main stem approximately 4 km upstream from the weir. As a result, the watershed consists of two nearly parallel subwatersheds.

Flooding occurs regularly but is not a significant problem. The major effect of flood flows is to make roads impassable at stream crossings and to inundate low-lying areas close to the stream channel. Low-lying areas do not make up a significant portion of the watershed or of many farm units. However, the flood-producing storm systems do cause other problems. The limited relief results in slow surface runoff, and the claypan soil limits internal drainage. As a result, agricultural operations are hindered by wet fields, although inundation from the stream does not occur.

Current Farm Management Systems

Goodwater Creek watershed includes portions of Boone and Audrain counties, with most of the watershed falling within Audrain County. The ranking of crops according to average harvested area is soybeans, hay, wheat, corn, and sorghum in Boone County, and soybeans, wheat, corn, sorghum, and hay in Audrain County. Typical crop rotations in the watershed are corn-soybean, corn-soybean-wheat, and sorghum-soybean-wheat. Annual fertilizer and pesticide use was estimated at 17,000 metric tons in Boone County and 29,000 metric tons in Audrain County during the 1977–88 period. A detailed survey of landowners will be conducted to obtain the information needed to evaluate historical cropping patterns, crop management practices, and fertilizer and pesticide use in the watershed.

Water management systems are not widely used in the watershed. No subsurface drainage facilities are known to

exist. Surface drains do exist, but they are usually incorporated into topographical modifications of the field rather than as specific diversion systems. Terraces and surface diversions are not generally needed. Irrigation is not widespread, but pivot systems are used on some farms.

Project Objectives

The Missouri MSEA project has seven major objectives.

1. Assessment. Measure the effects of conventional and alternative farming systems on surface and ground water quality.

   Sub-objectives are to evaluate the effects of farming systems on hydrology, erosion, dissolved nitrogen and pesticides in surface runoff, ground water, and chemical movement within the crop root and unsaturated zones. The potential ecological impacts of water quality associated with current and alternative farming systems will be assessed.

2. Component. Study the mechanisms responsible for the fate and transport of agrichemicals in soil and water.

   Sub-objectives are to evaluate the effects of basic soil and plant processes on pesticide fate and transport; determine the effects of basic soil processes on development of macropores and cracks and their effect on water flow; determine the effects of interflow over a claypan on pesticide and dissolved nitrogen fate and transport in the upper root zone; and determine the effects of riparian zones on the fate and transport of pesticides and dis solved nitrogen.

3. Scale. Determine how information from the plots and fields can be scaled up to watershed and regional levels.

   A sub-objective is to determine differences in measured responses between large and small watersheds and to identify the causes.

4. Modeling. Develop and refine models of the physiochemical, economic, and social processes of farming activities that affect soil and water contamination. Sub-objectives are to evaluate selected water quality models to verify their reasonableness and validity relative to measured values for claypan soils; improve the accuracy of model predictions by developing new components representing processes not presently modeled; and develop model components that predict macropore and crack flow as influenced by wetting and drying, freezing and thawing, and other basic soil processes.

5. Prescription farming. Develop and evaluate alternative cropping systems and technologies designed to protect water quality through the use of site-specific management techniques.

   Sub-objectives are to quantify and automate the measurement of in-field spatial variability in soil properties and crop yield; to develop methods to efficiently manage and utilize spatial data; and to implement systems using spatial data to precisely control pesticide and fertilizer application rates.

6. Socioeconomics. Establish the relative profitability of alternative farming systems and determine farmers' attitudes toward adoption of these systems.

   Sub-objectives are to measure the potential impacts of watershed-wide adoption of alternative farming systems and practices on production, farm income, and water quality and to assess the impacts of the MSEA project on landowners' and farmers' attitudes and behaviors regarding the use of alternative farming systems and the activities of local conservation districts, SCS, university extension services, and other related agencies.

7. Extension education. Develop education programs to increase farmers' awareness and understanding of the relative profitability and environmental benefits of alternative farming systems.

   Sub-objectives are to conduct workshops and demonstrations to inform farmers, extension specialists, soil conservationists, and legislators about the profitability and effects on water quality of alternative farming systems; and develop publications and other educational materials to inform farmers, regulators, and extension specialists about research results.

Research Design

Farm Management Systems

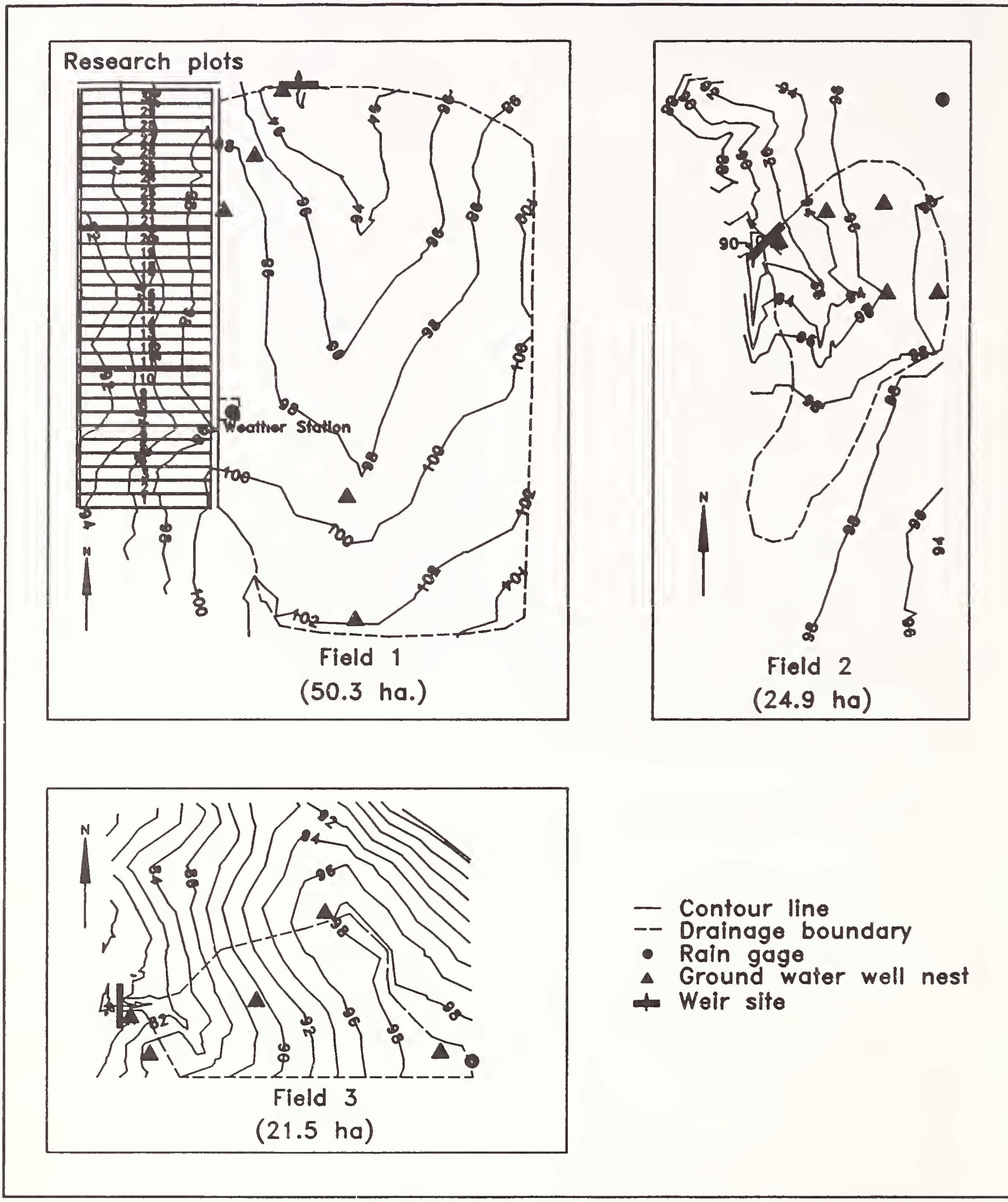
Field farming systems. The following three farming systems will be evaluated on field-sized areas of 20–50 ha.

- High agrichemical system, consisting of a corn-soybean rotation with high fertilizer and herbicide applications for high-yield production (farming system 1).

- Medium agrichemical system, consisting of a sorghum-soybean rotation with fertilizer and herbicide applications based on a long-term average yield and an emphasis on profitability (farming system 2).

- Low agrichemical system, consisting of a corn-soybean-wheat rotation with nitrogen fertilizer applications based on long-term average yields, soil testing, split fertilizer application, and a combination of herbicide banding and secondary tillage for weed control. Emphasis will be on profitability and water quality (farming system 3).

Figure 8. Instrumentation and topographical features of the Missouri MSEA field sites



Nitrogen fertilizer inputs will vary across the farming systems, whereas potassium and phosphorus will be applied to all systems based on yield goals and soil testing. Applications of leachable herbicides—atrazine and alachlor—will be graded from high to low in farming systems 1–3 by varying the application rates in systems 1 and 2 and by a combination of banding (to reduce herbicide applications) and secondary field cultivation in system 3. Primary tillage will be similar among farming systems. Crop scouting and recommendations for insect and disease control will be made by the University of Missouri-Columbia Integrated Pest Management staff. Primary emphasis in the three fields will be on assessing the impacts of the farming systems on surface and ground water quality and on evaluating their economic viability. Farming systems 1–3 were initiated on fields 1–3, respectively (fig. 8).

Plot farming systems. The high and low agrichemical farming systems will also be evaluated on plots that have summit, sideslope, and footslope soils represented in each plot (0.3-ha plots). Three additional farming systems will also be evaluated on plot-sized areas: (1) high agrichemical, no-till corn-soybean rotation; (2) low agrichemical, ridge-till corn-soybean rotation; and (3) no agrichemical, continuous grass without harvest (like the Conservation Reserve Program).

The emphasis of plot research will be on evaluating farming system and landscape variability on crop yields and root-zone soil and water quality. Plot results are not intended to provide a comprehensive evaluation of ground water quality.

The research approaches described next will be driven by and correspond to the seven previously stated project objectives.

Assessment

Five well nests will be installed within each field and ground water will be sampled for measurement of atrazine, alachlor, and dissolved nitrogen concentrations. Each nest will comprise two to four wells based upon the depth to bedrock. Wells less than 7.5 m deep will be sampled quarterly; deeper wells will be sampled annually.

An automated weather station located in the farming system 1 field will measure precipitation, climate, and chemical concentrations in rain. Rainfall will be measured on the two other fields using recording rain gauges.

Each field will be instrumented with a weir, a water stage recorder, and a refrigerated pumping sampler to measure on an event basis erosion and concentrations and losses of dissolved nitrogen, phosphorus and pesticides.

Crop uptake of nitrogen will be measured and related to nitrogen fertilizer inputs to assess the efficiency of fertilizer use.

EPA will do a toxicological analysis of runoff samples to determine whether surface water contains elements that are hazardous from an ecological viewpoint. EPA will also use a computer-based model to determine and assess the potential impacts of agricultural chemicals on ecological processes and conditions.

Component

The influence of macropores and soil cracks on the preferential flow of water and chemicals will be studied in the laboratory and field. Much of the research will focus on better understanding the processes affecting the formation of macropores and soil cracks. Techniques to be used include dyes, helium gas flux, and computed area tomography. Grid lysimeters will also be used to obtain detailed information on seasonal pathways and cycles of pesticide adsorption, movement, and persistence.

Pesticide degradation associated with row cropping and proximity to crop roots will be studied in the laboratory and field using herbicide compounds labeled with carbon–14.

Herbicide persistence cells placed at various depths in the soil profile to the depth of rooting will be used to monitor changes in herbicide persistence as a function of depth in the soil profile. Herbicide persistence will be related to soil moisture, temperature, and chemical characteristics, and the microbial communities present at the depths.

Nitrogen and oxygen isotopes will be used to determine the quantity of nitrate from fertilizers in ground and soil water in clay-rich materials. Existing isotopic signatures and fertilizer spiked with nitrogen–15 will be used to trace nitrogen fertilizers in the soil and ground water. Samples of runoff, soil water, rainfall, and ground water will be analyzed for nitrogen–15 and oxygen–18 to trace fertilizers. Changes in isotopic signatures are expected to reveal the extent of nitrification and denitrification. New laboratory methods will be developed and tested to determine oxygen–18 in nitrate and to significantly decrease the cost of nitrogen–15 analyses, making nitrogen–15 analyses an affordable tool in nitrogen studies.

Transpiration along the flow system by riparian vegetation near the discharge zone may be an important component of ground water discharge. Water level recorders will be used to examine transpiration-induced fluctuations in the diurnal water table. Instrumentation will be installed in Goodwater Creek to determine if the ground water discharging into the creek has lower concentrations of dissolved chemicals than do wells located upslope of the riparian zone.

Scale
Precipitation and climatic variables from a class A weather station will be measured within the 6,730-ha watershed. The spatial distribution of rainfall will be measured over the watershed using recording rain gauges.

The watersheds of 2,330-, 3,370-, and 6,730-ha are each instrumented with a weir and a water-stage recorder. Each weir will be instrumented with a refrigerated pumping sampler to measure chemical concentrations and losses on an event basis.

The main tool for aggregation will be mathematical modeling, surveys, and geographic information systems (GIS's). Scale studies involving surface water will include models such as AGNPS, which aggregates many cells to form a watershed. Mathematical modeling of ground water movement at the aquifer scale will include a field-scale area as a single node. Surveys will establish current farming systems and chemical use in the watershed. A geographic information system will generate input data and display output data from the mathematical models and other analyses.

Economic and environmental assessments of agricultural policies will be evaluated at the farm and watershed scales. Specifically, potential economic and water quality effects of using alternative farming systems throughout the Goodwater Creek watershed will be evaluated by integrating mathematical optimization models, physical process models, GIS's, and detailed farm surveys. Tradeoffs between farm income, soil conservation, and improvement in water quality will be evaluated at the farm scale.

Modeling
Several mathematical models will be examined to identify the strong and weak points of each. New knowledge gained from component research will be incorporated into key models to improve the accuracy of their predictions. Examples include macropore and crack formation induced by wetting and drying, freezing and thawing, and root proliferation within the soil. Hydrologic components will be modified to represent the influence of interflow over the claypan as well as the influence of saturated soil on chemical fate and transport.

The physical and chemical data sets will be used to validate model predictions against measured variables and to evaluate the effect of modifying the models to better represent existing processes or to represent new processes.

A chance-constrained programming model will be used to identify farming systems that maximize net farm income and consider the impacts of water quality.

Model applications will be facilitated by the development and use of GIS interfaces.

Prescription Farming
Spatial variability of soil properties and grain yields will be quantified and analyzed to determine the measurement scales required for the application of site-specific technologies.

Measurement and control systems and components will be developed and subjected to engineering performance tests in the laboratory. Once performance characteristics are documented and optimized, systems will be integrated for field evaluation, primarily at the field level.

MSEA data will also be used in the development and demonstration of systems for the management and utilization of spatial variability data.

Socioeconomics
Sociological surveys will be used to identify and evaluate (1) current cropping systems and uses of agricultural chemicals, (2) farmers' attitudes and behaviors regarding pollution of surface and ground water by agricultural pesticides and fertilizers and the use of alternative farming systems, and (3) personal and social facilitators and barriers to the adoption of farming systems that improve water quality.

Ethnographic research methodologies will be combined with quantitative modeling and survey information for farmers in and outside the Goodwater Creek watershed to assess the adoption behaviors of land operators. Specific factors to be examined include existing farming practices, agricultural chemical application rates, criteria used in making decisions regarding adoption of technologies and techniques, attitudes toward ground water problems, perceptions of environmental degradation associated with production agriculture, access to technology transfer systems, personal characteristics of owner-operators, institutional barriers to and facilitators of adoption, and characteristics of farm enterprises.

Economic models will be used to evaluate the profitability of current and alternative farming systems. Cost and return budgets will be used to estimate net returns for individual farming systems that protect water quality.

A mathematical programming model will be used to evaluate the effects of variations in crop yields, crop prices, and farm and resource conservation policies on the efficient choice of farming systems. Of particular interest are (1) policies that enhance planting flexibility by not penalizing farmers for using crop rotations and less chemically intensive farming practices and (2) policies that restrict the use of agricultural chemicals and encourage the adoption of alternative farming systems.

Education
The University of Missouri Extension Service, with its educational resources and academic expertise, will transfer economic and environmental information gained from MSEA research to farmers, extension specialists, soil conservationists, and legislators. The information will be used to promote better understanding by the general public of water quality concerns and issues.

The MSEA extension education coordinator will work closely with MSEA project managers, scientists, and other staff to enhance the usefulness and understanding of MSEA project research findings. Efforts will also be made to collaborate with county, state, and Federal agencies to disseminate MSEA research results, as well as to coordinate water quality education and information activities. Dissemination will be through workshops, conferences, demonstrations, and newsletters.

Research Products

Products of the assessment phase of research will include new knowledge and information on how alternative farming systems affect (1) surface runoff and erosion, (2) chemical transport and fate within the root, vadose, and ground water zones, and (3) farmer-landowner perceptions of economic and water quality benefits of the farming systems. The data will help MSEA and other state and Federal personnel to better understand the effects and interactions of climate, soil, topography, geology, and cropping and management practices on the variables measured in this phase of the research. Measured variables will also be useful in validating a number of natural resource models, particularly those which predict the movement of agricultural chemicals in the environment. This information will be used to produce bulletins and guides for use by conservation and extension personnel in educating farmers and the general public and to draft technical journal articles to distribute findings to other scientists.

Component research will focus on mechanisms and processes responsible for chemical fate and transport in the environment, which will result in journal articles for use by the scientific community. Other products will be theoretical, empirical, and statistical equations that will be used to improve a number of natural resource research and user models. Component research results will add to the general understanding of agricultural chemical and alternate farming systems impacts, and this knowledge will be incorporated into bulletins and technical guides for use by state and Federal agency personnel, farmers, and the general public.

Results from scale research will be useful to state and Federal personnel in determining how changes in farming systems will affect surface runoff, subsurface flow, erosion, chemical movement within a project area, as well as farm production and income. The research includes assessing how changes in the spatial distribution of farming systems within the project area will influence variables of interest. Data obtained from this research will be used to help develop mathematical models that can be applied to project-sized areas.

Products originating from modeling research will include mechanistic, stochastic, and statistical equations and models that will generally improve existing equations and models. Because of the complexity of the claypan soils and the influence of the clay layer on physical, chemical, and biological processes, many of the equations and models will be used to describe the influence of the claypan on processes that affect chemical transport and fate. These products will take the form of verified and validated equations, subroutines, and models and accompanying documentation. Other expected products will include procedures to integrate GIS data to replace input files normally read into a model to provide soil, topography, and cropping and management data. Other equations and models will be developed to better predict the influence of farming systems on social and economic variables important to the adoption of alternative farming systems.

Products from prescription farming research include the development of new engineered systems for site-specific farming and the knowledge required to implement these systems. Emphasis will be placed on technology that appears promising for eventual use in production agriculture. Efforts will be made to transfer this technology to commercial uses, where appropriate.

The socioeconomic component of the project will focus on developing products that enhance the social acceptability and economic profitability of alternative farming systems and, ultimately, the likelihood that farmers will adopt alternative farming systems.

The education component of the project will focus on transferring research findings to user groups such as farmers, extension specialists, soil conservationists, legislators, and the general public. Specific products include papers, newsletters, annual field days, workshops, bulletins, and guides.

Nebraska MSEA

Project Goal

The goal of the research being undertaken at the Nebraska MSEA is to develop and evaluate cropping systems and farming practices that reduce or halt ground water contamination while providing profitable management alternatives to farmers.

Site Description

The principal project site is in Nebraska's Central Platte Valley, a region where more than 90 percent of the land is under cultivation. Over 75 percent of the cropland is devoted to the continuous production of irrigated corn and about 10 percent is devoted to irrigated soybeans.

The area is experiencing serious ground water contamination, as indicated by the ever-increasing number of municipal wells that exceed acceptable nitrate levels. The ground water beneath more than 200,000 contiguous ha between the cities of Kearney and Columbus in the Platte Valley has nitrate-nitrogen levels greater than EPA's maximum contaminant level for public water supplies. The contaminated area is expanding by more than 4,000 ha each year.

The increased risk of ground water contamination associated with irrigation necessitates special pesticide, nitrogen, and water management considerations. The production systems demonstrated and management practices researched in the Nebraska MSEA project emphasize irrigated cropping systems, and these same management strategies apply throughout the region. The availability of irrigation in Nebraska and other North Central States provides an opportunity to respond to crop nutrient needs via fertigation. Technologies developed in the Nebraska MSEA project for assessing crop nitrogen status will apply throughout the region and can be used in conjunction with surge or sprinkler irrigation, as well as with spoke injection techniques on high-clearance vehicles.

Location

The principal project site is in the Central Platte Valley near Shelton, NE, on the river terrace about 4 km north of the Platte River. The site consists of four 13.3- to 16-ha "management blocks" and a 32-ha field for component research under both sprinkler and furrow irrigation. A 64-ha buffer area separates the management blocks and the component research area (fig. 9).

Geology

The principal aquifer in the area consists of shallow Quaternary fluvial silt, sand, and sand and gravel deposits that are 15–18 m thick. Directly beneath the Quaternary deposits is a 6- to 12-m-thick clayey silt-retarding zone that regionally occurs above the Ogallala Formation (Miocene) in this part of Nebraska. This clayey silt acts as a partially confining layer to the more permeable deposits in the Ogallala Formation. The Ogallala generally ranges between 12 and 18 m thick and consists of interbedded silts, poorly consolidated sandstones, and thin gravel lenses.

Soil

The predominant soil is a Hord silt loam with small areas of Hall and Wood River silt loams and Blendon loam. The Hord soils have a thicker, more friable, and less clayey B horizon than the Wood River soils and a more friable and less clayey B_2 horizon than the Hall soils. Hord soils have a finer-textured B horizon than the Blendon soils. Beneath all soils at the site is sand at a depth of 120–150 cm.

Weather and Climate

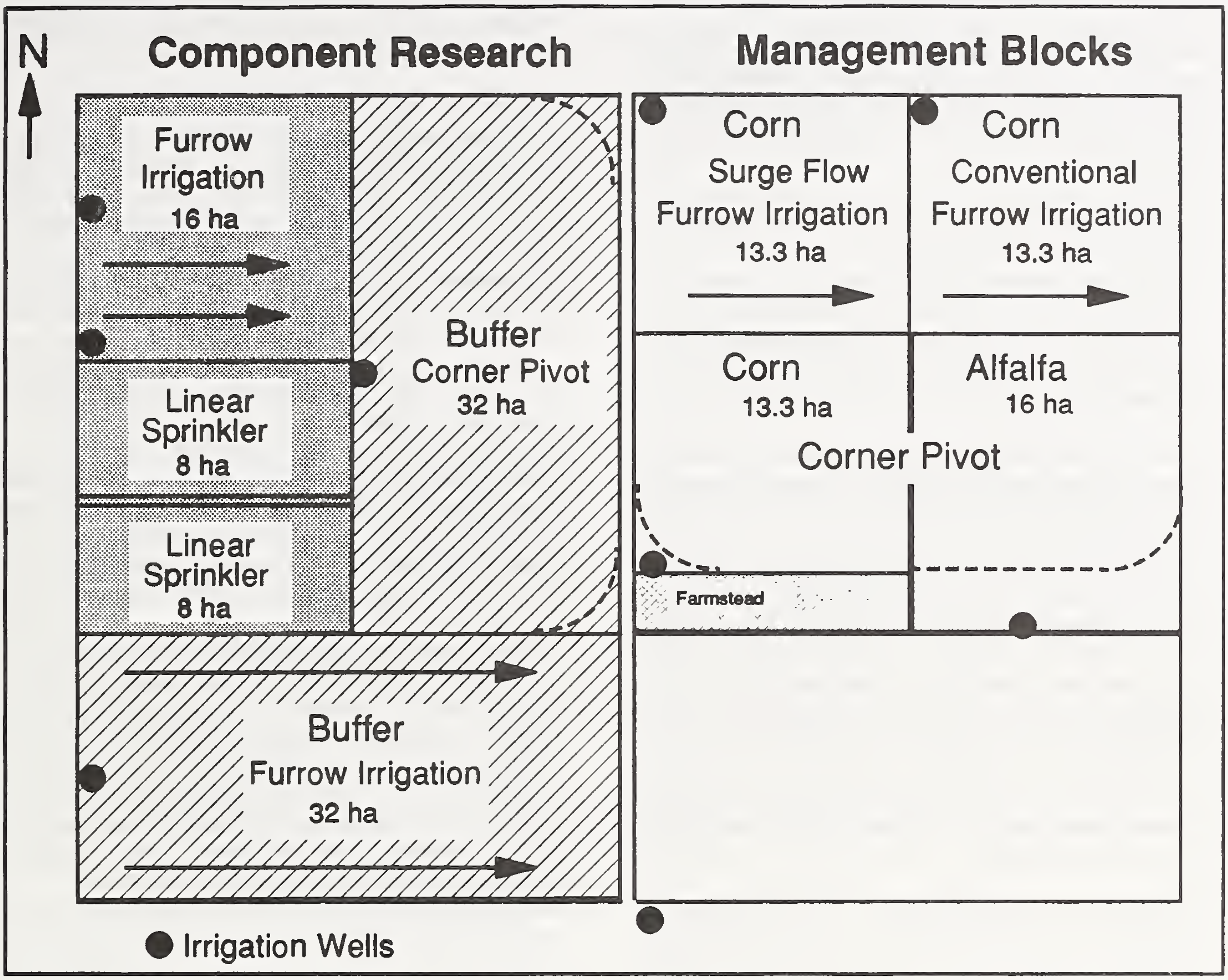
Long-term weather records from a class A station are available from Grand Island, NE, about 40 km east of the MSEA site. Similar data are available at the Kearney station about 35 km to the west. About 11 km from the MSEA site, a fully automated station has been providing hourly averages of wind speed and direction, temperature, relative humidity, solar radiation, and soil temperature since 1980. An automatic recording station will be installed at the site, and additional rain gauges will be placed across the management blocks and the component research area.

Agrichemical leaching is strongly influenced by percolation amounts, which are dependent on soil type and chemical and irrigation management. Annual precipitation at the MSEA site averages 61 cm, with 42 cm falling during the May–September growing season. Evapotranspiration during the same period is 60–70 cm. Seasonal irrigation amounts typically range from 43 cm on silt loams to 135 cm on sandy soils, and net irrigation requirements average 28 cm and 38 cm, respectively. As a result, in-season deep percolation ranges from 15 to over 100 cm, depending on soil type and irrigation method. Off-season percolation amounts typically range from 5 to 15 cm.

Hydrology

Ground water flow is east-northeast. The Platte River is a losing stream through much of the Central Platte region. During periods of high flows (spring and early summer), it supplies recharge to the adjacent shallow aquifer, instead of receiving ground water inflow. Depth to ground water across the MSEA site is seasonably variable from 4.5 to 7 m during the pumping season. During dry years in the late 1970's, the depths to ground water were about 1 m greater.

Figure 9. Representation of the Nebraska MSEA site, indicating the type of irrigation used and the direction of flow



A 1974 ground water quality survey revealed that nitrate-nitrogen levels in the area around the MSEA site averaged 18 mg/L. Nitrogen isotopic studies indicate that agronomic sources accounted for most of these levels, not animal or human wastes. The pesticides atrazine and alachlor have also been detected in ground water in the immediate vicinity of Shelton. Atrazine levels ranged from below detection to 3.1 µg/L in the ground water beneath the terrace and from below detection to 88 µg/L in the bottom land ground water.

The loading of inorganic and organic chemicals into the aquifer was estimated using data from nested monitoring wells installed in 1977 in a 4,000-ha area 2.4 km south of Shelton near the Platte River. Elevated nitrate, dissolved organic carbon, and atrazine levels were found in shallow wells downgradient from irrigated fields and were vertically stratified within the primary aquifer. Stratification reflected recent loading, with the highest concentrations in the shallowest wells. Nitrate-nitrogen levels exceeding 100 mg/L have been reported in some shallow monitoring wells between the towns of Shelton and Wood River.

Current Farm Management Systems

The current farming system at the MSEA site (as in the entire area) is dominated by irrigated corn production with an occasional rotation into soybeans. Irrigation water at the site is supplied by one well per 16-ha field. Well capacities range from 50 to 75 L/sec. Furrow irrigation is used, with an average length of run of 400 m. Normally, every row is watered on a 12-hr set. Runoff is controlled by diking the end of the field, so that all runoff soaks into the ground within the field. Water may collect for a distance of 90 m or more in the field behind a dike.

There is little runoff of precipitation from the farm prior to the irrigation season. The flat slopes (nearly equal to a 0.1 percent gradient) and the internal system of field roads and dikes hold runoff on the field. This approach to runoff

management for irrigation and precipitation contributes significantly to the potential leaching of agrichemicals in general and of nitrate-nitrogen in particular.

In the absence of significant rainfall, irrigation water is applied weekly. The first irrigation of the season (usually in early July) is the heaviest, with typical amounts ranging from 15 to 20 cm. Subsequent irrigations are on the order of 10–15 cm.

Project Objectives

The specific research objectives are enumerated next.

1. Compare the net effects on ground water quality of conventional and alternative management systems for irrigated crop production.

2. Increase knowledge about the fate and transport of agricultural chemicals under conventional and improved irrigated production systems.

3. Develop and evaluate new technologies for managing pesticides, nitrogen, and irrigation to reduce ground water contamination.

4. Develop models and decision-making systems to aid farmers in choosing management strategies that are environmentally sound and profitable.

5. Identify and analyze the social and economic factors that influence the acceptance and use of management options for improving water quality.

6. Evaluate the economic impacts on the farm and estimate the economic impacts on the region of alternative management practices to improve water quality, including household income and aggregate economic output.

7. Develop a "nitrogen budget" for the various management systems to evaluate fertilizer efficiency and the potential for nitrate leaching.

Research Design

Research will focus on (1) farm management systems at the field level, (2) ground water monitoring and assessment, (3) component research to extend knowledge of the fate and transport of agricultural chemicals under various management scenarios, and (4) assessment of socioeconomic factors affecting adoption of alternative management strategies.

Farm Management Systems

Three 13.3-ha management blocks at the principal site will be dedicated to the evaluation and demonstration of available technology packages for water, nitrate, and pesticide management on irrigated monoculture corn. Each technology package will be used as a single treatment on a block. Each block provides enough land area for full-scale demonstration and evaluation, as well as detection of treatment-associated changes in ground water quality.

The three technology packages to be compared are (1) current farm practice, (2) best management practices with surface irrigation, and (3) best management practices with sprinkler irrigation. The impact of these best management practices on ground water quality will be evaluated directly through the use of multilevel sampling devices and indirectly through periodic sampling of the soil and water through the vadose zone. All three management blocks will have the same pesticide program.

The current practice block will receive a preplant application of ammonia without nitrification inhibitor, banded atrazine at planting for weed control, and conventional furrow irrigation with 12-hr continuous sets and end-of-field diking in lieu of tailwater recovery. The amount of fertilizer nitrogen will be estimated according to guidelines that define a reasonable yield and account for residual nitrate in the soil and the nitrate content of the irrigation water.

The block dedicated to best management practices with surface irrigation will receive laser-guided land grading, alternate-row surge irrigation, tailwater recovery, and irrigation scheduling according to crop water use. Any preplant ammonia will be applied with a nitrification inhibitor. Fertilizer nitrogen will be reduced below current guidelines to take advantage of nitrogen mineralization through the growing season. If proposed furrow irrigation fertigation techniques are perfected in time, seasonal nitrogen application may be split. The herbicide to be applied at planting time will be banded atrazine.

The block dedicated to best management practices with sprinkler irrigation will be served by a center pivot system with a corner unit. Irrigations will be scheduled according to measured crop water use. A soil water deficit will be maintained to provide for storage of rainfall. Nitrogen applications will be split among a small preseason ammonia application if appropriate, with a nitrification inhibitor, and incremental applications via fertigation, with the latter based on results from frequent tissue testing. This innovative approach will minimize the nitrogen application required for good production and the residual nitrogen available for leaching in the off-season. The herbicide treatment will be the same as that used on the surface irrigation block.

A fourth 16-ha treatment block will be seeded to alfalfa. This block is expected to provide maximum removal of nitrate from the soil and irrigation water. It is also expected to indicate the upper limit of the ability to positively affect ground water quality through management practices.

As mentioned previously, the impact of treatment will be directly evaluated through ground water monitoring and vadose zone sampling. Indirect estimates will be made by evaluating the amount and distribution of irrigation water and the runoff volume of surface irrigation.

Ground Water Monitoring

Because of lateral ground water movement beneath the MSEA site, a uniformly managed "buffer zone" will be established on the upgradient side of the 16-ha blocks to ensure an inflow of relatively good quality, shallow ground water. The high background levels of agrichemical contaminants in the ground water will make it difficult to monitor changes in contaminant levels resulting from applications on the overlying soils. Success will depend on managing the upgradient buffer zone to minimize nitrate and atrazine loading from the crop root zone in that area.

As the buffer becomes a relatively nitrate- and atrazine-free recharge zone, transport of these contaminants downgradient to the shallow ground water beneath the research site will be minimized. Accordingly, detection will be maximized of changes in nitrate and atrazine levels in the shallow ground water beneath the research blocks. Estimates will be made of the inflow and outflow fluxes at plot boundaries under varying management scenarios.

Installation of monitoring equipment will be done in phases. In 1990, several multilevel samplers-piezometers were installed. The resulting data will be used to define the localized water table and the areal and vertical flow at the site. Water will be collected from multilevel samplers at various depths below the water table and analyzed.

In 1991, additional sites were selected and each was instrumented with eight dedicated and sealed multilevel Solinst samplers-piezometers. The close areal and vertical spacing of these samplers should provide the data necessary to adequately assess the relative efficacy of the management alternatives. To facilitate analysis, field data on aquifer characteristics, well location, and pumpage will be used as inputs to a model of ground water flow.

The Nebraska district of the U.S. Geological Survey and researchers from the University of Nebraska Geology Department will help characterize the hydrogeologic system in the vicinity of the MSEA site. This study will provide a detailed definition of the hydrogeologic framework and will quantify the movement of water into, through, and out of the ground water system. The Geological Survey will attempt to develop techniques for continuous indirect monitoring of nitrate concentrations in the top few centimeters of the saturated zone. This work will be supplemented by deep soil coring conducted under the EPA nonpoint-source research program through the Nebraska Department of Environmental Control.

Component Research

While work is in progress on the management blocks, associated research will develop new practices or improve components of existing ones. Two 16-ha blocks will be established for plot research adjacent to the management blocks, one under sprinkler irrigation and one under furrow irrigation. Intensive trials will be conducted for 4 years of the 5-year MSEA program.

Associated research to develop best management practices and evaluate system components will also be conducted at six satellite locations: (1) ARS Central Platte Valley site; (2) sludge injection site, Grand Island, NE; (3) South Central Research and Extension Center, Clay Center, NE; (4) West Central Research and Extension Center, North Platte, NE; (5) Kansas State University research farms, Manhattan and Scandia, KS; and (6) Fremont, NE injection site.

This strategy has several advantages: It (1) allows researchers to take advantage of MSEA field sites with long-term histories of rotations and tillage studies (Clay Center, Manhattan, and Scandia); (2) provides a fully instrumented installation of monolithic lysimeters for direct measurement of nitrate and pesticide leaching under monoculture corn and corn-soybean rotation (North Platte); (3) capitalizes on ongoing nitrogen management research (ARS Platte Valley); and (4) provides an established research location where major nitrate contamination of a shallow aquifer is being studied (Grand Island). Given the time required for the root zone environment to stabilize under significantly altered management systems, the satellite locations will perform evaluations that could not otherwise be done at the MSEA site within the timeframe of the program.

Other ongoing studies (funded separately) with similar soils near the demonstration site will provide information on the effectiveness of winter cover crops in reducing leaching of nitrogen-tagged fertilizer between fall and spring. This site will also provide needed information on the relative sensitivity of various corn hybrids to nitrogen stress (using tissue analysis and leaf chlorophyll determinations), thereby indicating how to integrate such considerations into nitrogen management and fertigation strategies.

Specific research related to cropping systems will include the economic and agronomic feasibility of crop rotations, cover crops, and several scavenger crops. Nitrogen metabolism research will build on recent findings, addressing the effects of nitrogen stress on the phenology and physiology of corn for the purposes of characterizing cultivars and developing crop-monitoring techniques that will optimize fertigation and nitrogen management strategies. Crop nitrogen research will be integrated with nitrogen mineralization studies in the laboratory, under field conditions, and through use of simulation models to address the dynamics of crop residue, manure, and municipal waste decomposition as related to crop nitrogen needs. Concepts involving

nitrogen mineralization, fertilization, and crop nitrogen requirements will be integrated with surge and sprinkler irrigation research to develop optimum strategies to meet crop nitrogen and water requirements while minimizing nitrate and pesticide leaching below the root zone.

Solute transport studies will evaluate the potential impact of research treatments on ground water quality, using vadose-zone sampling of the soil and soil solution. Herbicide in-situ biodegradation and retardation studies will be conducted. Attention will be given to spatial variability of water and chemical movement. The impact of chemigation on chemical movement in soil affected by preferential flow is largely unquantified and must be evaluated concurrently with demonstration activities. The fate of pesticides under different management systems will receive special attention, along with evaluation of alternative weed control programs using less mobile herbicides and reduced quantities of chemicals.

Socioeconomics

The farmer's adoption of almost any new practice will probably require capital investment, may result in reduced income, and will certainly require changes in management systems. Careful economic analysis is needed to determine which practices offer the most cost-effective water quality improvements. Intensive economic study is also needed to evaluate the farm-level and regional implications of any major changes in management practices and production systems required to meet water quality goals.

Concurrently, implementation of needed management changes must proceed at a reasonably rapid rate within the context of an economically acceptable farming system. Although extension activities have clearly increased the rate of adoption of new technology, changes in production practices have frequently lacked strong farmer acceptance. For the MSEA program to have a large impact, research and extension personnel must thoroughly understand the barriers to farmers' acceptance of new technology and must focus their research and education programs on innovative production systems that integrate producer and environmental concerns.

Three components of the socioeconomic analysis—farm-level economic effects, regional economic effects, and sociological assessment—will provide policymakers with essential information for balancing potential tradeoffs between water quality improvements and the socioeconomic effects at the farm, regional, and national levels.

The research tasks associated with the farm-level economic analysis are

- to select and define model farm situations;
- to evaluate alternative economic optimization models;
- to collect data on production practices, yields, costs, and prices; and
- to use optimization models to conduct farm-level analysis of best management practices and other farming systems, given certain assumptions regarding future agricultural policies.

Under regional economic analysis, the research aims are

- to define multicounty regions for analysis;
- to determine procedures for extrapolating regional results from the model farm;
- to collect and aggregate data, including acreages, by soil type, land use, and farm size;
- to estimate the aggregate consequences of actions affecting water quality at the farm level, including measures of production, use of production inputs, and net returns;
- to construct input-output models for assessing the impact of changes at the farm level on the regional economy; and
- to assess the regional economic consequences of water quality programs, including output, household income, and employment.

Tasks under sociological and attitudinal research are

- to select issues for analysis, including preliminary identification of factors likely to influence the adoption rate of alternative management practices;
- to conduct focus group interviews of producers to obtain data for developing a formal survey questionnaire and for compiling information on attitudes toward alternative management practices;
- to prepare a questionnaire (mail or telephone) for use in quantitatively assessing attitudes toward alternative management practices;
- to select a sample of producers and conduct the survey; and
- to analyze survey results and develop recommendations concerning the management practices most likely to be accepted by producers and the public policies most likely to be effective in improving water quality.

A comprehensive assessment of alternatives to the water quality program will be made following completion of these sociological tasks. The assessment will summarize the

tradeoffs between water quality improvements and socio-economic consequences at farm and regional levels.

Research Products

Expected products from the Nebraska MSEA research are listed following:

- A ranking of the environmental effectiveness of various joint management strategies for water, nitrogen, and pesticides. The users will be farmers, extension agents, resource district personnel, regulatory agency personnel, and irrigation equipment dealers.

- A combined ranking of strategies based on economic and environmental factors. Users will be farmers, extension agents, resource district personnel, regulatory agency personnel, and irrigation equipment dealers.

- An arsenal of vadose and ground water data that describes the transport of agrichemicals and that can be used in designing improved practices and in technology transfer. Users will be researchers, extension agents, resource district personnel, and regulatory agency personnel.

- Techniques for strategically placing nitrogen and irrigation water to reduce the risk of nitrate leaching. Users will be farmers and extension agents.

- Fast and reliable tissue analysis techniques to evaluate crop nitrogen status and develop nitrogen management practices involving fertigation. Users will be agricultural consultants, farmers, extension agents, fertilizer dealers, and researchers.

- Fertigation technology to provide acceptable nitrogen distribution under furrow irrigation using surge technology. Users will be farmers, extension agents, and fertilizer dealers.

- Innovative cropping systems using scavenger and cover crops to minimize nitrate leaching. Users will be farmers and extension agents.

- Innovative sensing devices and advanced programming packages to improve operation of surge and conventional surface irrigation systems, to reduce irrigation amounts, and to improve water distribution. Users will be farmers, resource district personnel, extension agents, and irrigation equipment dealers.

- Improved understanding of nitrogen and pesticide movement in soil and the vadose zone. Users will be researchers and regulatory agency personnel.

- Innovative advances in instrumenting and sampling the vadose zone and ground water. Users will be researchers, resource district personnel, and regulatory agency personnel.

- Predictive models for unsaturated and saturated transport. Users will be researchers, resource district personnel, and regulatory agency personnel.

In addition, we anticipate the publication of many scientific journal articles covering the entire range of project objectives.

Ohio MSEA

Project Goal

The goal of the Ohio MSEA project is to develop improved agricultural systems that will reduce ground water pollution from fertilizers and pesticides while providing practical and profitable farming methods.

Site Description

The Ohio MSEA site is located on a farm overlying the Scioto River Buried Valley Aquifer. Buried valley (or alluvial) aquifers are typically shallow, permeable, and unconfined and have high recharge rates. These aquifers exist along most streams and rivers in the midwestern United States and have become a major source of water for public consumption. The aquifers are vulnerable to surface contamination because they embody short flow paths to the water table, which decrease the potential for adsorption, for chemical reactions between contaminants and minerals in the soil, and for biodegradation. In Ohio, ground water pumped from buried aquifers serves the domestic water needs of about one-third of the population.

Soils overlying the alluvial aquifers are well drained and highly productive. With the increased use of fertilizers and pesticides during the 1980's to maintain high agricultural yields, poor water quality has become more pronounced. In a recent study, more than 16,000 private wells in 76 of Ohio's 88 counties were tested for concentrations of nitrate-nitrogen. Although the site of the Ohio MSEA—Pike County—was not included in the study, the adjacent counties had high average levels of the compound.

Location

The Ohio MSEA site is primarily located on the 263-ha John Van Meter farm located approximately 3 km south of Piketon and southwest of the intersection of U.S. Route 23 and State Route 124. The farm is bounded on the north by State Route 124 and on the east largely by U.S. Route 23, although some of the land to the east includes the junction of Little Beaver Creek and Big Beaver Creek, which are east of U.S. Route 23. On the west the farm is bounded primarily by the Scioto River. The Ohio MSEA has leased 50 ha of the farm for this study.

Geology

The bedrock valley beneath the floodplain of the Scioto River was the principle course of meltwater drainage from Pleistocene glaciation. Flowing meltwater carried rock debris (which the glaciers eroded from exposed bedrock) and deposited it as nearly homogeneous layers of outwash across the valley floor. In the MSEA area, these deposits are 22–25 m thick and consist chiefly of sand and medium-sized gravel, with lesser amounts of silt and localized lenses of clay.

The valley is more than 2 km wide. Ohio shale forms the walls of the river valley and upland hills, as well as the base of the eroded valley, which is partially filled with the alluvial and outwash deposits. The water table normally ranges from 3 to 6 m below the surface and the saturated thickness of the aquifer ranges from 18 to 20 m.

Soil

The terraces (first and second bottoms of the Scioto River Valley) consist of soils classified as Fluscutic Hapludolls. Infiltration occurs readily, allowing rapid recharge of precipitated water into the aquifer, along with any chemical constituents.

Weather and Climate

A precipitation gauge is located 4 km north of the MSEA site; a precipitation and temperature station is located at Waverly, OH, approximately 16 km north of the site; and a weather station and a meteorologic tower are located at the Department of Energy enrichment facility approximately 5 km southeast of the site. The Waverly station has weather records extending back to 1936.

Hydrology

The aquifer has a supply potential of 5.6 million m^3/day and is typical of other alluvial aquifers in Ohio and the Midwest. The soils overlying the aquifer are highly permeable, with vertical and horizontal saturated conductivities of 15 m/day and 150 m/day, respectively. A 15-cm diameter well (of the Ohio Department of Natural Resources) with a continuous record since 1969 is located within 3 km of the MSEA site.

The average transmissivity of the aquifer is more than 3,000 m^2/day and the specific yield is about 0.2 $m^3\ m^{-3}$. The saturated thickness ranges from 18 to 20 m. Rainfall that percolates to the aquifer under the site recharges to the Scioto River except during extreme flooding.

Wells in the vicinity include two high-volume water supply wellfields—one about 4 km north of the MSEA and the other 3.5 km southwest. The combined abstraction from the two wellfields is about 75,000 m^3/day. There is also a low-volume wellfield located less than 1.5 km southwest of the MSEA. None of these wellfields directly affects the MSEA.

The susceptibility of bottom land to flooding is not expected to pose a serious problem. A levee protects the bottom terrace from floods, which occur about every 5 years. However, the Ohio MSEA site is located on the upper terrace, which floods about every 20 years. The most severe flooding in the Scioto River basin occurred in 1913, but since then, flood control structures constructed along the

Scioto River have diminished flood impacts. No crop damage from flooding has occurred on the site since 1937. Even during severe floods, flow velocities in the flood plain are less than 0.6 m/sec.

Several wetland areas exist on site. These areas consist of bottom-land hardwood wetlands adjacent to the Scioto River, natural emergent wetlands (abandoned slough associated with the Scioto River), and "jurisdictional wetlands" associated with "wet spots" in the agricultural fields of the lower terrace. These wetlands reduce flooding, cleanse waters, protect river banks, and recharge the unconfined aquifer in the Scioto River Valley.

Water Quality

There are no point pollution sources identified in the area and no major industries in the vicinity. Although a Department of Energy enrichment facility is located to the southeast, it has had no identified impact on the MSEA bottom land. Effluent and cooling water from the facility discharge south of the facility or into Little Beaver Creek.

Extensive information is available on the inorganic water quality of the aquifer, and the water is routinely analyzed for radioactive constituents. However, only limited information is available on organic and inorganic agricultural chemicals. A 1989 study reports relatively high levels of nitrate in private wells in similar buried valley aquifers in Ohio. The Department of Energy has indicated its willingness to share with the Ohio MSEA group its extensive pumping and water quality records for the wellfields.

Current Farm Management Systems

During the period 1984–89, the land was farmed with soybeans, corn, and wheat. Because of the high permeability of the soil and the relatively deep water tables, no subsurface drainage systems are located on the farm. The topography is very flat, with an average slope of less than 0.1 percent.

Historically, the MSEA site has not been irrigated. During the period 1987–90, some limited irrigation was done to the south and southwest of the MSEA, using a center pivot system; in 1990 a 40-ha area to the south was irrigated while under seed corn production.

Project Objectives

The objectives of the Ohio MSEA project are listed following:

1. To characterize the baseline hydrogeologic, geochemical, and geomicrobial environments of the buried river valley aquifer at the Ohio MSEA, in the Piketon region, and in each of the research plots;
2. To assess the effects of the different farming systems on the ecological, hydrogeologic, geochemical, and geomicrobial environment of each system;
3. To determine the dynamic and spatial leaching fluxes of applied pesticides and nitrates under different agricultural management systems;
4. To determine crop production responses to the different agricultural management systems;
5. To determine the expected profitability of each commodity produced under each alternative agricultural system and the variability of profits;
6. To identify areas in the region in which to establish the most promising alternative agricultural systems and then to assess the likely benefits of the systems in the locations;
7. To determine socioeconomic factors affecting the adoption of alternative agricultural management systems;
8. To develop practical predictive models and systems for identifying the effects of an agricultural management system on water quality at specific sites, as well as the production levels and profitability of the system;
9. To augment existing agricultural data bases related to water quality; and
10. To disseminate MSEA research results and provide technical assistance to farmers who are implementing new farm management systems.

Research Design

Agricultural Management Systems

Three farming systems will be evaluated.

1. Continuous corn will be tilled with a chisel plow. The herbicides used will be atrazine and alachlor. Nitrogen will be applied at a rate of 180 kg/ha.
2. A corn-soybean rotation will use no-till for the corn and chisel plow for the soybeans. Herbicides for corn will be atrazine and alachlor and for soybeans, alachlor and metribuzin plus chlorimuron-ethyl. Nitrogen at a rate of 180 kg/ha will be applied to the corn phase of the rotation.
3. This system will be a ridge-till corn-soybean-hairy vetch rotation, with banded herbicide application. Nitrogen application for corn will consist of residual nitrogen from the vetch cover crop and manure. The

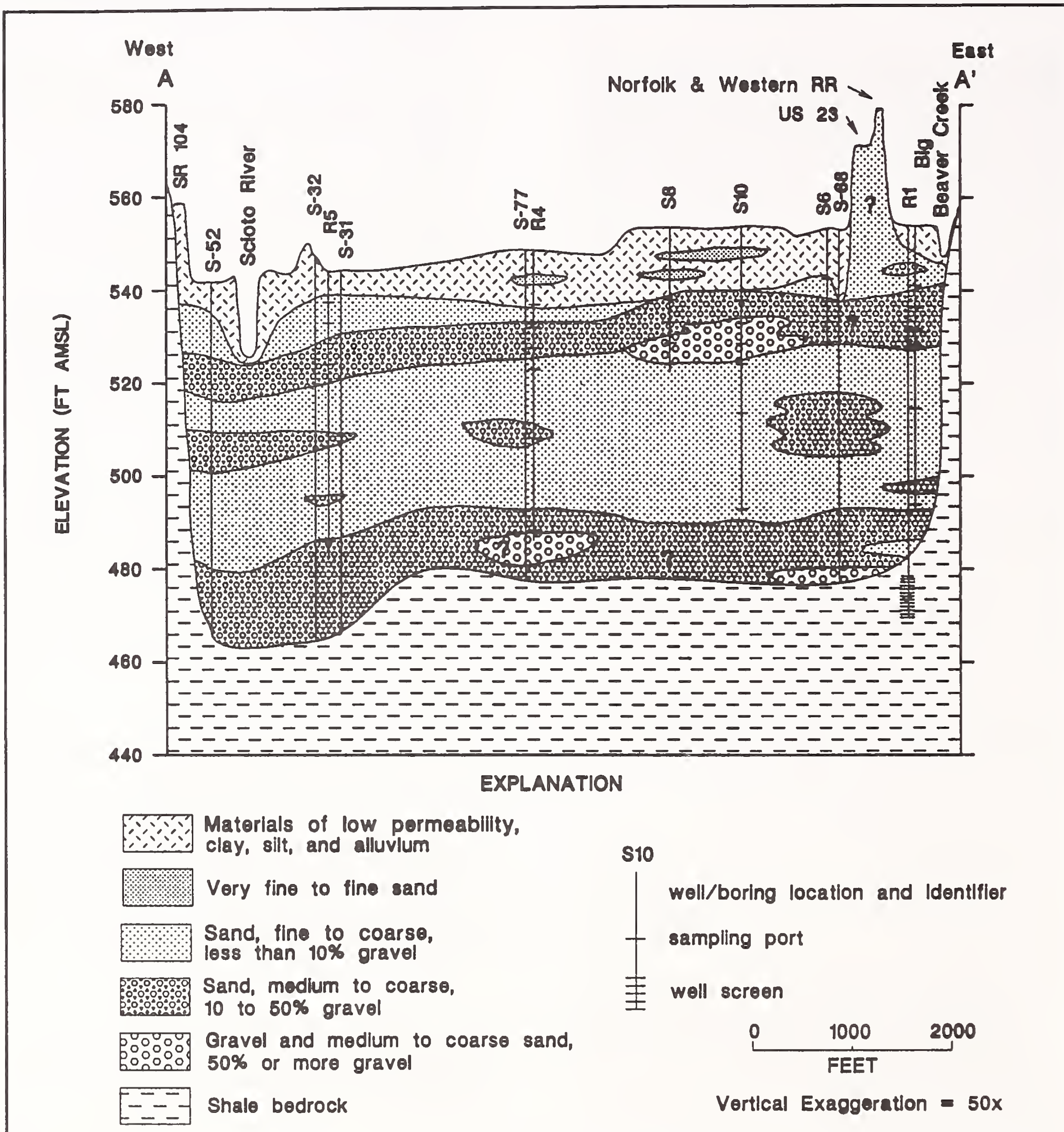
manure will be applied at the rate of 56,122 L/ha, and supplemental anhydrous ammonia will be applied for a total nitrogen input of 130 kg/ha.

In all three systems, nicosulfuron and quizalofop will be used to control johnsongrass.

In order to conduct saturated flow research, each farming system will be established on a separate 10-ha field. Space and resource constraints will prevent replicating these large fields, but small plot replicates will be maintained nearby in order to obtain statistically valid measurements for research other than the saturated flow research. Figure 10 shows a general layout of the plots.

The small treatment plots will be arranged randomly in a complete-block statistical design; each plot will be 0.4 ha. One of the following treatments will be assigned to each

Figure 10. Layout of the study plots and well locations at the Ohio MSEA site



plot: (1) continuous corn, (2) corn phase of a corn-soybean rotation, (3) soybean phase of a corn-soybean rotation, (4) corn phase of a corn-soybean-wheat cover rotation, (5) soybean phase of a corn-soybean-wheat cover rotation, and (6) wheat cover phase of a corn-soybean-wheat cover rotation.

Each plot will be bordered by an untreated strip approximately 10 m wide and planted in a cover crop such as grass. The border strip will allow equipment to work the plot and will minimize overlapping effects of treatments. A 5.5-ha area has been set aside to conduct research on alternative farming practices.

Core Data Collection

Core data will be collected for application to many of the specific research activities and for use in evaluating hypotheses that apply to the State of Ohio and the region. The Ohio hypotheses are similar to the regional hypotheses and are described following:

- Hypothesis 1: Aboveground biomass does not differ significantly among management systems.
- Hypothesis 2a: Aboveground biomass nitrogen does not differ significantly among management systems.
- Hypothesis 2b: There is no significant difference in nitrogen output from the three crop management systems.
- Hypothesis 3: Losses by surface runoff are not significantly different among the three management systems in terms of (1) soil, (2) nitrate, (3) pesticides.
- Hypothesis 4: Root biomass and root biomass distributions are not significantly different among the management systems.
- Hypothesis 5: The physical properties of the soil, the number of macropores, and the numbers of microorganisms are not affected by management practices (1) in the root zone and (2) below the root zone.
- Hypothesis 6: Water content and distribution in the unsaturated zone is not significantly different among management systems.
- Hypothesis 7: There are no significant differences among the management systems in the concentrations of nitrate and pesticide residues collected in the unsaturated zone (1) in the root zone and (2) below the root zone.
- Hypothesis 8: Microbial numbers and diversity in the saturated zone do not differ significantly as a result of different management systems.
- Hypothesis 9: There are no significant differences in the amounts of nitrates and pesticides in the ground water as a result of the three management practices.
- Hypothesis 10: Economic profitability does not vary among the tested management practices.

Economic Evaluation

Data that will be routinely collected are dates of planting, emergence, and harvest; plant populations; dates the plants reach specific growth stages; pesticide application dates and rates; fertilizer and manure application dates and rates; price received for each commodity; seed use; the machinery required for pesticide application, reason for application, and time needed to apply; labor hours; depreciation of equipment; land values; interest rates; and a summary of expenses from MSEA's and commercial farms in the region using similar agricultural practices.

Crop Production System

Two automatic Campbell weather stations have been placed at the Ohio MSEA. One station will be located adjacent to the research plots and the other near the Department of Energy wells southwest of the plots. These weather stations will provide data on precipitation, air temperature, relative humidity, solar radiation, wind speed and direction, and soil temperature. A daily precipitation gauge will be located at the MSEA site. A wet-dry collector will be used to obtain composite precipitation samples.

Root distributions will be sampled seasonally at the first reproductive stage. At randomly selected locations in each plot, three soil cores will be taken between rows and three within the rows at depths of 0.0–0.05 m, 0.05–0.15 m, 0.15–0.3 m, and 0.3–0.45 m. Once during the season, plants will be dug in order to compare the soil-core root biomass with the plant root biomass. Root biomass will be determined by weighing the samples after overnight oven drying.

Aboveground biomass will be obtained monthly from three 1-m strips of row (in cover crops from a 0.76-m^2 quadrant) that are randomly selected in each plot. The samples will be weighed, then two plants will be separated into components and oven dried overnight, and the dry mass recorded. The dried sample will be used for nitrogen and carbon content analysis. Leaf area will be measured indirectly by relating the weight of a known leaf area to the weight of the sample.

Canopy cover will be recorded photographically from a predetermined location in each plot. Crop height will also be recorded.

The grain from each plot will be handled separately, and final yield will be recorded at harvest. The grain will be weighed, its moisture content measured, and its quality assessed. A sample of the grain will be evaluated for nitrogen content. In order to compare total grain yields across the plots, combine losses will be quantified.

Pest infestation and plant damage will be quantified using scouting and standard assessment techniques. Recent residue cover will be recorded in the spring and fall in all replicate plots, using the line transect method.

Hydrologic Processes

Temporal and spacial changes will be monitored in the quantity and quality of surface, unsaturated, and saturated water flows. Water samples will routinely be analyzed for pesticides, fertilizers, tracers, and organic and inorganic chemical content.

Unsaturated flow. Water content distribution in the unsaturated zone will be monitored on a biweekly basis. Water content data will be collected by using a combination of soil cores and a neutron probe and frequency domain reflectometry (FDR). Soil cores will be collected monthly from each plot at depths of 0.0–0.15 m and 0.3–0.45 m. Access tubes installed in each large plot will enable readings to be taken from the neutron probe and FDR. Using one of these methods, readings will be taken biweekly at depths of 0.0–0.15 m, 0.3 m, 0.9 m, and 1.5 m.

To monitor chemical movement in the unsaturated zone, soil cores and porous-cup suction samplers will be used. Soil cores 25 mm in diameter will be obtained, handled, and analyzed using regional quality protocols. The cores will be taken at replicate locations in each plot at the following intervals: prior to spring tillage; 2 weeks past planting; in corn at silking and at physiological maturity; and in soybeans at R1 flowering, R6 full seed, and 2 weeks following each fertilizer application.

Pesticide and nitrate information will be obtained from soil cores at depths of 0.0–0.15 m, 0.15–0.3 m, 0.45–0.6 m, and 0.85–1.0 m.

Saturated flow. The monitoring scheme for the saturated zone will quantify ground water flow and quality on two scales and is designed to be integrated with the monitoring scheme in the unsaturated zone. The local or regional scale monitoring network is designed to collect data at the research site and adjacent upgradient areas. The primary function of the network is to collect data that reflect land use practices beyond the boundaries of the research fields and to provide information on chemical migration from the research fields to the Scioto River. These data will show changes in ground water levels that will be used in determining local variations in the directions of ground water flow and in flow velocities, as well as upgradient (background) ground water chemistry data.

The other scale—the block or site scale monitoring network—will be designed to collect data from the individual 10-ha fields in the study site to identify differences in ground water chemistry among the three management systems. This network will also monitor changes in ground water flow directions and flow velocities among the 10-ha fields.

Thirty-seven wells were installed in the Ohio MSEA. These include 11 water table wells, 4 bedrock wells, and 22 multiport wells. The locations for the wells or well groups are shown in figure 10. All wells were installed with the cable tool method, which allowed continuous sampling of the aquifer materials. During installation, every 1.5 m was cored using an oversized split-spoon sampler 0.1 m in diameter. The cores were split into subsections for laboratory analysis by specific research activities.

The water table wells each have a 6.7-m PVC screen that straddles the water table. The wells are instrumented with incremental encoders that continuously monitor water levels to detect recharge events to the aquifer. Water table wells in the center of the three 10-ha fields and the wells located near streams are also instrumented with probes that continuously measure specific conductance and temperature. Data from these probes will augment the detection of recharge as it reaches the water table.

The bedrock wells each have a 3.3-m PVC screen, the top of which is 1.5 m below the top of competent bedrock. Care was taken to ensure the wells were sealed from the overlying drift aquifer. Each well contains an encoder to monitor water levels in the bedrock aquifer located below the alluvial aquifer. Hydrographs from the bedrock, alluvial, and surface water will be compared to evaluate the interactions of ground water and surface water and of bedrock water and alluvial water.

Multiport wells are used to obtain water quality samples from various depths of the alluvial aquifer. These wells have stainless steel sampling ports and dedicated pumps at 3.7 m, 4.9 m, 6.1 m, and 7.3 m below land surface. Selected wells also have additional sampling ports at 12.2 m and 18.3 m below the surface. Backfill around the wells includes two grades of pure quartz sand. A coarse sand was placed around each sampling port and a fine sand was placed midway between sampling ports to deter vertical movement of ground water. No bentonite seals were used in the well construction since organics tend to adhere to bentonite and could alter the ground water chemistry.

Research Products

This section lists the anticipated end products from the specific research activities at the Ohio MSEA. Research results will be disseminated to appropriate audiences in the following forms: technical reports, theses, dissertations, journal articles, fact sheets, technical bulletins, field days, demonstrations, slides, and videos.

- An economic evaluation of the alternative production systems used in the Ohio project.
- Greater understanding of the effects of the farming systems on the biological processes taking place in the soil and on ground water quality.

- Characterization of the soil's physical and hydrological properties.

- Better understanding of the microbial and chemical processes that affect the fate of pesticides in surface and subsurface environments.

- The hydrogeological, geochemical, and geomicrobial characterization of a buried river valley aquifer.

- A regional characterization of land use and water quality.

- Establishment and evaluation of core data bases for the region and the Ohio MSEA.

- Development of ways to predict the willingness of land operators in the Scioto River Basin to adopt water quality protection practices.

- Review of existing models and development of new models that simulate the processes and effects of cropping and management systems used in the Ohio MSEA.

- Development of models that simulate the water and solute transport in the soil matrix and along preferential flow paths.

- Refinement of a hydrologic and water quality model and application to MSEA activities.

- Determination of temporal changes in chemical loading rates to the saturated ground water flow system from alternative corn and soybean production systems.

- Evaluation of general and pesticide DRASTIC maps as planning and management tools in agriculture land use activities.

- Refinement and extension of GIS and cartographic modeling to incorporate subsurface water quality problems and phenomena.

- Incorporation of an education component as part of the Ohio MSEA research.

- Evaluation of the effectiveness of constructed wetlands for improving water quality in an agricultural landscape.